Technical Memo

ANL/EES-TM-295

THE TRANSPORTATION ENERGY AND EMISSIONS MODELING SYSTEM (TEEMS): SELECTION PROCESS, STRUCTURE, AND CAPABILITIES

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by

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Energy and Environmental Systems Division
Center for Transportation Research

November 1985

work sponsored by

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FOREWORD

Under the auspices of the National Acid Precipitation Assessment Program (NAPAP), activities supporting the preparation of future assessments have been planned and delegated to task groups. Task Group B (TG-B), "Man-Made Sources" (subsequently redesignated Task Group I, "Emissions and Controls"), of the Interagency Task Force on Acid Precipitation is responsible for developing and testing models that can be used to project fuel use and air-pollutant emissions by energy use sector. Argonne has participated in the TG-B program since 1984.

The TG-B program is being carried out in two phases. Phase 1 includes development of the models for generation of baseline scenarios. Phase 2 will address the capabilities for modeling emission-control scenarios. Under Phase 1, the sector models are being developed and tested. This testing is designed to aid in model development and help prepare the models for use by the task force. Upon completion, the sector models will be incorporated into the TG-B emissions model set and linked to a system of models that provide scenario-consistent input data.

The Argonne Energy-Economic Modeling Program is publishing a series of reports that document the selection, development, and execution of two end-use sector models. This report is part of this series; it documents the steps undertaken to represent the transportation sector by a model capable of forecasting emissions by pollutant category and state between the years 1980 and 2030. This model is designated as the Transportation Energy and Emissions Modeling System (TEEMS).

ACKNOWLEDGMENTS

This report about the Transportation Energy and Emissions Modeling System (TEEMS) is only a shell; past efforts giving rise to the progress documented herein have erected the modeling system's superstructure, and those primarily responsible for such efforts deserve mention here. Unless otherwise noted, the persons acknowledged are current or former employees of Argonne National Laboratory (ANL). M.P. Kaplan, Y.J. Gur, V.B. Mendiratta, and A.D. Vyas (together with consultants C.L. Hudson and I.E. Harrington) comprised the core group responsible for developing (over the three-year period 1980-82) the algorithms or the original set of individual activity models that later became the TEEMS. A.D. Vyas, M.E. Millar, K. Tsunokawa, and A.J. Zielen enhanced the capabilities of these models and undertook the first steps toward unification of the procedures under a single aegis. Finally, D.A. Hanson and others responsible for conceptualizing and fleshing out the National Acid Precipitation Assessment Program (NAPAP) Task Group B modeling scheme provided the needed impetus for assembling the TEEMS in its current form. Thanks to all these people -- as well as to numerous professionals in the field of transportation analysis, both internal and external to ANL, who have contributed useful ideas to the process -- the TEEMS is now a reality.

I thank R. Rykowski and L. Platte of the U.S. Environmental Protection Agency (EPA) Mobile Sources Laboratory in Ann Arbor, Michigan, and P.D. Patterson of the U.S. Department of Energy (DOE) Office of Transportation Systems (Assistant Secretary for Conservation and Renewable Energy) for knowledgeable and incisive review of the two discussion papers (Nos. 1 and 10) for NAPAP Task Group B that gave rise to the present document. For his guidance and perceptive review throughout the project, H.W. Hochheiser of the DOE Office of Planning and Environment (Assistant Secretary for Fossil Energy), the principal sponsor of the work that linked the activity and emissions modules of the TEEMS, is especially to be thanked. Also greatly appreciated is the past and present interest and support of D.O. Moses of the DOE Office of Environmental Analysis (Assistant Secretary for Environment) and P.D. Patterson, each of whom originally sponsored development of most of the discrete activity model components.

D.A. Hanson and D.W. South of ANL have provided ongoing direction and useful commentary during my preparation of the earlier discussion papers and the current document. The result is a product of higher quality than would have been the case without their participation. Beyond this, all errors of fact or judgment are the responsibility of the author.

THE TRANSPORTATION ENERGY AND EMISSIONS MODELING SYSTEM (TEEMS): SELECTION PROCESS, STRUCTURE, AND CAPABILITIES

by

Christopher L. Saricks

1 INTRODUCTION

In the National Acid Precipitation Assessment Program (NAPAP), Task Group B (TG-B) is responsible for developing and testing models that can be used to project fuel use and air-pollutant emissions by energy use sector. As discussed in the Foreword, this work is being carried out in two phases. All activities described in this report have taken place under Phase 1 of the program. This report addresses the Transportation Energy and Emissions Modeling System (TEEMS), one of the sector models developed by Argonne for inclusion in the TG-B emissions model set (see Fig. 1). The report documents the recommendation of TEEMS as the transportation-sector model in the TG-B emissions model set and defines its configuration for test runs planned under Phase 1.

This introduction provides a brief overview of the emissions modeling and forecasting activities for mobile sources (transportation) required as part of the TG-B emissions model set, Phase 1 activities. Both the needs and the objectives of this component of the model set are described. The report that follows presents these objectives, describes a framework suitable for achieving them in an appropriate and efficient manner, evaluates a number of approaches against this framework, and selects from among these approaches the one that appears most closely to meet the needs of Phase 1, in terms of both reliability (accuracy) and integrability into the overall model-set scheme (Fig. 1).

1.1 BACKGROUND AND PURPOSE

The objectives for modeling transportation source emissions in the TG-B emissions model set may be stated as follows:

1. Develop an inventory of oxides of nitrogen (NO_x), volatile-organic-compound (VOC), and sulfur dioxide (SO_2) emissions arising from transportation activity in the continental United States for the years 1985, 1990, 1995, 2000, 2010, 2020, and 2030;

2. Employ, in the development of these inventories, forecasting/allocation techniques capable of estimating these emission totals state by state;

3. Incorporate within the forecasting scheme the capability to model the effects of currently programmed, planned, or potential

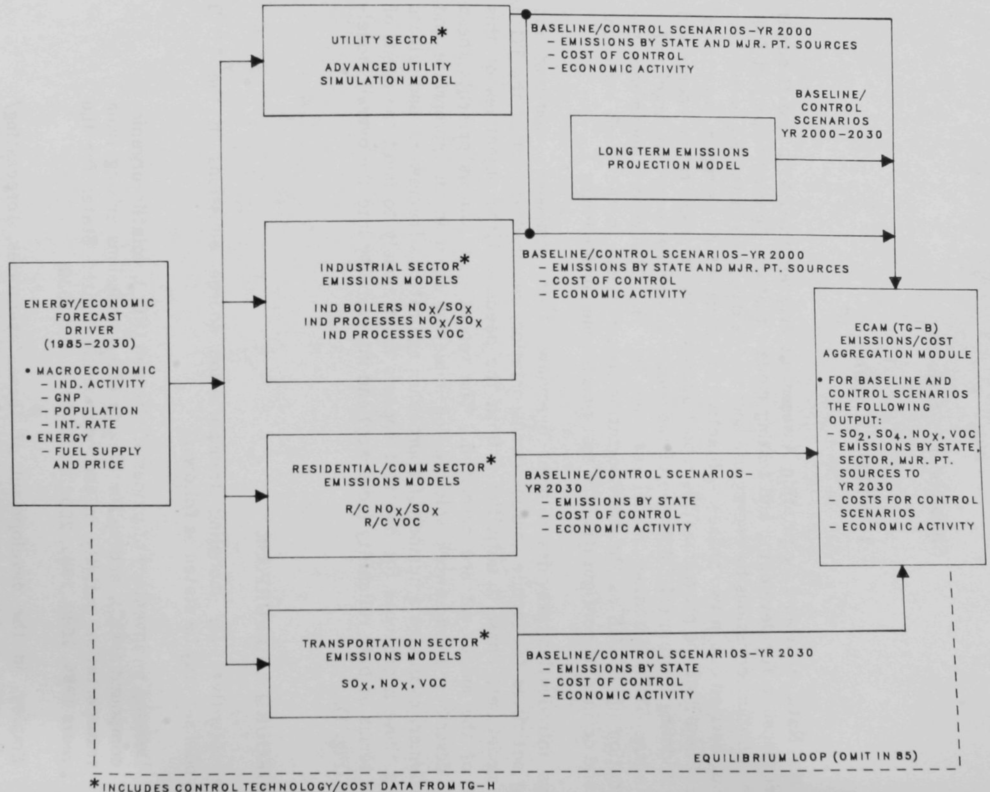

FIGURE 1 TG–B Emissions Model Set

vehicular emission-reduction strategies on the total pollutant loading (relative to a baseline projection), with particular attention to the date(s) of implementation of these incremental controls and their expected stringency.

Figure 1 shows how this transportation emissions task fits into the general organizational scheme of the TG-B emissions model set. Figure 2 provides more detail on the place of this task within the forecasting scheme; all sector models are driven by a consistent set of energy and economic projections for the test runs planned in Phase 1. The box in Fig. 2 representing the transportation emissions-forecasting component could legitimately be partitioned into several discrete components of travel activity with respect to travel demand, modal (vehicular) share, and type of movement. These components are as follows:

- All local personal travel, both that occurring within Standard Metropolitan Statistical Areas (SMSAs) as defined in 1980 and other (non-SMSA) travel;
- Intercity personal travel by ground and air modes (business and nonbusiness);
- Commercial and rental automobile and light-truck travel;
- Interurban -- including port-to-port -- goods movement (coupled with intraurban distribution); and
- Other aviation (including general, military, and international travel).

Because the demand for transportation service in any one of these cells may have only a weak dependence on -- or even virtual independence from -- the demand in any of the other cells, the approach to transportation forecasting within the emissions model set cannot be simplistic. Instead, the approach must consider all important differences in transportation activities, relying on the energy/economic driver to set the initial conditions for each component of the forecasting model. In order to illustrate how a transportation emissions-forecasting system can meet these requirements for the Phase 1 test runs, and to provide appropriate detail on the criteria used in the selection of a candidate transportation modeling process, this report will systematically cover several topical areas, in the sequence described below.

1.2 ORGANIZATION OF REPORT

Section 2 reviews candidate transportation-activity forecasting systems. The general techniques suitable for the scope and mission of the test runs in Phase 1 are addressed first, followed by the specific criteria for selection of a technique or techniques. The models reviewed for this analysis (based on fulfilling one or more of the

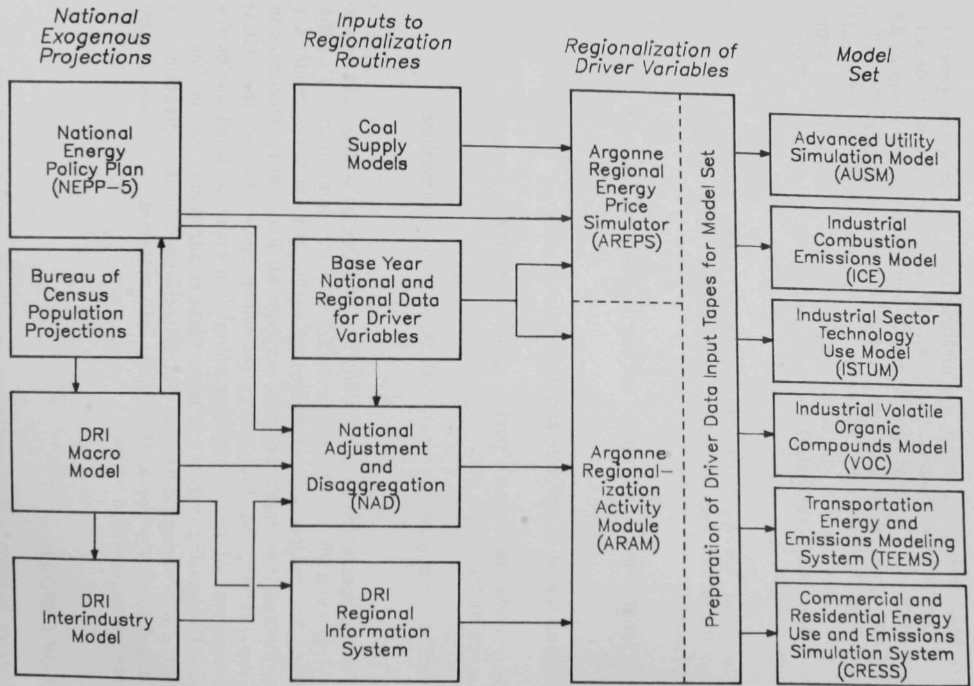

FIGURE 2 Details of the Energy- and Economic-Forecast Driver for the TG-B Emissions Model Set

selection criteria) are discussed in turn. The section concludes with an identification and justification of the modeling system recommended as being the best choice in light of these criteria.

Section 3 provides a detailed account of the structure of the recommended system by component model (or submodel), and shows which transportation activities are accounted for (and how this is done) by each component. Issues of spatial resolution and temporal detail are also covered. Sections 4 and 5 present the recommended emissions-computation module and discuss its integration with the set of activity models. Section 6 describes the features and capabilities of the total recommended system in general, in light of the requirements of the Phase 1 test runs. This is followed by a more specific discussion of potential emission-control scenarios for the transportation sector and how the system could address each of them.

Section 7 documents an effort to replicate the 1980 NAPAP inventory with the recommended transportation modeling system. Finally, Section 8 identifies the steps remaining to make the modeling system fully capable of carrying out the requirements of the test runs in Phase 1 of the TG-B program. The completion of these steps, including making the model operational and interpreting the preliminary 1985 test results, will be documented and discussed in a forthcoming report.

Acronyms and initialisms appear throughout this report. Where they are first used, the complete terms they represent are provided. In addition, all such acronyms and initialisms used in the text are listed, with their meanings, in the Appendix.

2 MODEL REVIEW AND SELECTION OF A TRANSPORTATION MODEL

Ideally, any attempt to forecast transportation activity with a high degree of spatial and temporal reliability should employ the most sophisticated state-of-the-art procedures. Due to constraints of time and resources, however, this is not always possible, and so a middle ground of feasibility must be found. Section 2.1 presents a summary of the *best* available procedures for measuring and projecting urban and intercity transportation activity. Section 2.2 presents the most cogent criteria for selection of a model for application in the Task Group B emissions model set (Phase 1). In Sec. 2.3, some transportation models are examined that are both available and appropriate for inclusion in the TG-B model set, and the degree to which each has succeeded in approaching the "optimal" framework is also documented. Section 2.4 presents the recommended modeling scheme for forecasting transportation activity and related precursor emissions of acid rain.

2.1 STATE-OF-THE-ART TECHNIQUES TO FORECAST TRANSPORTATION ACTIVITY

Transportation activity is most intense at the urban or SMSA level. Between 70 and 80% of all trip-making occurs in urban areas and the areas immediately contiguous ("exurban rings"), which translates to about 60% of the total vehicle-miles of travel (VMT) by cars and trucks on the road. Because this travel, generally on trips of less than 100 miles, is undertaken on relatively congested roadways with frequent stopping and starting (on average) per unit distance, the average speed is far less than that achieved in most intercity trips of more than 100 miles, and therefore, the pollutant loading per mile of travel is greater. Thus, it is appropriate to distinguish VMT occurring in SMSAs and smaller urban areas from that occurring between cities and on rural highways. The techniques for modeling urban travel, which have moved toward greater realism in recent years, are discussed briefly below.

Forecasting automobile and mass-transit travel in urban areas has become a relatively sophisticated procedure that couples behavioral modeling with network- and graph-theoretical path building and flow simulation. Once the results of a modeling chain (or, in some cases, a direct demand model that simultaneously estimates trip generation, allocation, and mode of travel) have been calibrated to base-year data, projections of population growth and of future demographic and land-use distributions are used to define activity patterns and generate a zonal trip-origin/destination matrix for each mode. Trips are loaded from each zone onto a flow network of links and nodes that attempts to replicate the actual road and transit system of the region, together with planned new links and capacity improvements. Shortest-path and cumulative-impedance algorithms are used in route selection for each trip. Final output of the model for the projection year includes the future daily travel volume for each link in the network and the total impedance (volume/capacity ratio), leading to an estimate of average speed on that link. Because of a high probability of estimation error at the level of the individual link, computerized summation routines are used to reaggregate these data to a spatial grid prior to the computation of vehicular emissions or fuel consumption.

Although traffic simulations like those described above represent the best source of information on future urban-highway vehicular activity and emissions, their very complexity renders them unsatisfactory for examining the effects on future vehicular emissions of such phenomena as new technology introduction, fuel prices, alternative economic and population growth scenarios, and incentives for multioccupant travel. The consideration of *all* cities at this level of detail (which might be desirable for a 48-state emissions inventory) would be prohibitive, due to the enormous input data requirements and high production cost: for large networks, each simulation would cost up to $500 per scenario run for central-processing-unit (CPU) time alone. Thus, only a limited number of alternative systems could be simulated.

Metropolitan planning organizations are increasingly adopting the technique of "sketch" planning analysis for comparison of multiple policy and alternative variants, in which the coded "real" network is collapsed to a "spider" network that can abstract several parallel links as a single "superlink" with the combined capacities of the deleted links. These superlinks may remain along the grid alignments of actual roads, or they may be further abstracted to connect the centroids of the zones through which they pass, thus altering the plane coordinates of their endpoint nodes but retaining a coded length reflecting actual over-the-road distances. Sketch techniques sacrifice the microscale precision needed to evaluate, for example, carbon monoxide "hot spots," but they retain mesoscale accuracy and are far less expensive to use in policy testing than full network assignment (usually less than 10% of the cost). Of course, there is no concomitant reduction in the requirement for precision in the input data used to generate the change in actual travel.

Growth in commercial vehicular movement on the highways (intra- and intercity trucking) is not yet subject to similarly sophisticated forecasting techniques. A few metropolitan areas, notably Chicago and New York, have experimented with base-year truck-trip generation, distribution, and network assignment directly. For the most part, if trucks are included at all in simulation flows, their contribution to total traffic volume is estimated empirically from surveillance data; trucks are cast into the network -- piggybacked onto automobile flows -- as "passenger-car equivalents" for purposes of defining their impedance value. This practice makes it very difficult to identify discrete trucks *by size category* in a fully loaded urban network in order to isolate the pollutant emissions attributable to trucks. For convenience, a fixed percentage of VMT for each link or corridor category is usually allocated to each of the vehicle types assumed to be on the network; this distribution is then carried through in estimating a composite vehicular emission factor. Such a procedure becomes highly unrealistic in the travel-projection model, because assumed future VMT percentages by truck type reflect no methodology for generating future truck trips (but may be based on forecasted rates of change in car and truck registration by size class).

Additional detail on procedures and practices in transportation modeling is available from many textbook sources (see especially Refs. 1 and 2).

Forecasts of intercity truck movement are virtually nonexistent at the resolution required for modeling acid-rain precursor emissions. Growth rates in economic activity or truck registration constitute the principal indicators, but the usual unit of measure for freight movement -- ton-miles of travel -- is unsuitable for estimating emissions. Where efforts have been made to convert ton-miles to truck miles by size class (for emissions purposes, heavy vs. light truck and gasoline vs. diesel fuel), specific routing patterns have not been simulated.* It appears that only aggregate national projections for ton-miles of freight flows by commodity group are generally available, except in the case of California, which has commissioned a special study of this topic to assist the state in estimating its future transportation energy demand. Elsewhere, forecasts must rely on such data bases as the 1977 Commodity Transportation Study (CTS) (U.S. Bureau of the Census) in allocating freight flows by commodity to specific states and regions.[3]

Off-highway vehicular emissions have been estimated and forecasted by activity indicators suggested by such sources as the 1975 U.S. Environmental Protection Agency (EPA) report, *Methodology for Estimating Emissions from Off-Highway Mobile Sources for the RAPS Program.*[4] Table 1 presents some of the most common growth indicators and the source categories to which they have been applied for emissions forecasting and other purposes.

2.2 CRITERIA FOR SELECTION OF A TRANSPORTATION-ACTIVITY MODEL

Because transportation is an intermediate or joint good (i.e., it is demanded as a *means*, rather than an end) and because the consumption of fuel is, therefore, incidental to the purposes for which transportation activity is undertaken, it would be inappropriate to attempt to forecast emissions from mobile sources through a procedure or procedures designed primarily to forecast demand for petroleum. Moreover, the emission rates of on-highway motor vehicles (which account for about 80% of total emissions of NO_x and 87% of total emissions of VOCs from all transportation sources) are expressed in grams per mile of travel, and the travel-mile is a unit of activity (not fuel consumption). Therefore, the model selected for the test runs in Phase 1 should be able to project transportation activity in a way that is sensitive to changes in the most important factors contributing to that activity:

- Fuel price,
- Population growth,
- Shifts in household demographics,
- Gross national product (economic activity),
- Freight carrier costs and service, and
- Vehicular efficiency.

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*Although national freight networks and shipment-routing algorithms have been coded and used in various policy studies, modal definition *within* the truck class has not been a feature of such efforts.

TABLE 1 Some Key Indicators for Computing Emissions Changes

Off-Highway Source Category	Indicator						
	Fueling Changeover (equipment mix)	Change in Acres Under Tillage	Change in Employment in Relevant SIC[a] Category	Population Growth (also by age group)	Single-Unit Housing Growth	Ton-Mile Growth (apportioned)	Landing-Takeoff (LTO) Cycles
Agricultural equipment	x	x					
Heavy construction equipment	x		x				
Industrial equipment	x		x				
Off-highway motorcycles	x			x			
Lawn and garden equipment					x		
Rail freight	x					x	
Cargo aircraft	x					x	x
Vessels	x					x	
Recreational boating				x			

[a]SIC = Standard Industrial Classification.

Because such activity cannot be predicted in a vacuum, any model selected should make use of an empirical data base (appropriate to the modeling philosophy) from which changes can be projected. Ideally, this data base would be a time series, with the ability to guide predictions of the rate (as well as the absolute amount) of change. However, virtually all available national survey data with an acceptable degree of bias in the sample population are cross-sectional. Therefore, failure to incorporate time-series survey data into a forecasting baseline will not constitute a demerit a priori against any candidate model, if the model itself is well-specified with respect to an otherwise reliable data base.

The following criteria (in approximate order of importance) were applied in the selection of a transportation activity (and emissions) forecasting model from among the various candidates reviewed by Argonne National Laboratory (ANL):

1. Ability to replicate historical estimates of transportation-related emissions by modal activity, such as those available from the 1980 NAPAP transportation inventory, and to project future emissions (by mode) at a suitable level of detail;

2. Consistency with the energy/economic driver approach (Figs. 1 and 2) to sector modeling, such that changes in economic and demographic variables have a direct effect on transportation activity;

3. Disaggregation (i.e., household- or decision unit-based) of approach to travel modeling, such that individual types of decision makers are presented stimuli that cause them to undertake travel in a behavioristic framework rather than as a strictly monolithic response to aggregate indicators;

4. Ease of translation from transportation activity to total emissions;

5. Geographical resolution at the regional level or lower, without concomitant increase in resources required to prepare input data files;

6. Capability to model emission-control scenarios with expected (but not necessarily intuitive) directional sensitivities;

7. Capability to deal with new technology penetration and turnover in the transportation sector; and

8. Forecasting track record (i.e., prior application).

2.3 REVIEW OF APPLICABLE MODELS

The list of candidate models was initially limited by considerations of availability, past application, and flexibility appropriate to the Phase 1 test runs. Models were reviewed first by means of documentation prepared by or on behalf of their formulators and then, if possible, by consulting the conclusions of an independent review body on the merits and shortcomings of each. The most valuable example of the latter type of information source is the series of reports prepared by the Highway Safety Research Institute (HSRI) at the University of Michigan by a team under the direction of B.C. Richardson.[5] The reader is encouraged to refer to these reports for a more thorough discussion of most of the models cited below.

Models developed principally to forecast aggregate fuel consumption in the transportation sector use sectoral input/output forecasts to estimate rates of change in vehicle fleet registration and per-vehicle utilization. Vehicle-survival functions (the proportion of vehicles of a given prior model year still in operation in the current year) are usually embedded in the algorithm, making computation of age-weighted vehicular fuel consumption and emission factors relatively straightforward for any projection year. Some models have made use of high-quality time-trended national or statewide vehicle-registration or fuel-sales data, either to extract expected miles of vehicle travel from fuel-consumption statistics or to derive fuel consumption from direct estimates of travel activity; these derived relationships can be extrapolated into the future under any set of assumptions about changes in average vehicular fuel efficiency over time. None of these models is explicitly able (by itself) to treat the effect of differing speeds or climate on total emissions. (For NO_x emission rates, speed sensitivity is relatively low for light-duty vehicles.)

Five examples of such model types are: (1) the Transportation Energy Consumption (TEC) Model, developed over the period 1976-83 by Jack Faucett Associates (JFA); (2) the Highway Fuel Consumption (HFC) Model, developed over the period 1978-84 by Energy and Environmental Analysis, Inc.; (3) the State-Level Highway Gasoline and Truck Diesel Fuel Demand Models (HGDM), developed over the period 1978-82 by Oak Ridge National Laboratory (ORNL); (4) the Transportation Energy Conservation Network Model (TECNET), developed over the period 1977-81 by International Research and Technology Corp. and subsequently by the CONSAD Corp.; and (5) the Transportation Energy and Emissions Modeling System (TEEMS), developed at Argonne National Laboratory over the period 1980-84. All of these models have been developed for the U.S. Department of Energy (DOE). Documentation is available for all five models; however, it is not known whether the HFC and HGD models are yet in a final form acceptable to their developers.

2.3.1 Transportation Energy Consumption Model

The JFA TEC model uses econometric estimating techniques to forecast vehicle ownership and travel demand. Although it assumes retention through time of many relationships observed in the base case that might in fact change due to policy initiatives (e.g., the new vehicle size mix offered by specific manufacturers), it represents a relatively early systematic attempt to introduce income level, vehicle price, operating cost, and scrappage rates as important variables in determining the future profile of the highway vehicular fleet. Moreover, the model accounts for reduced vehicular activity with age and is adaptable to different levels of demographic or political-unit aggregation. It has been applied with some success to forecasting tasks for the U.S. Department of Energy. Therefore, the TEC model meets criteria 2, 5, 7, and 8 (Sec. 2.2).

The TEC model treats on-road vehicles only, and the diesel share of highway vehicles must be exogenously specified. Households are defined only by income level, rendering other significant demographic parameters irrelevant in the vehicle-choice process. The model has a poor track record in replicating either past market shares by vehicle type or past fleet profiles for automobiles. In general, the TEC model does not meet criteria 1, 3, 4, and 6 (Sec. 2.2). The HSRI analysis of the automobile component of the model labeled it a "weak forecasting tool" for projecting fleet composition and auto travel.[6]

2.3.2 Highway Fuel Consumption Model

The HFC model is an accounting procedure, driven by a macroeconomic forecast, that generates fuel-economy values, vehicle registrations, VMT, and fuel consumption by vehicle and engine type for light-duty vehicles (automobiles) and light- and heavy-duty trucks. The diesel share of fleet and VMT by vehicle type is separately reported, providing a means to distinguish gasoline from diesel power as an emissions source when vehicle-mile outputs are fed into an emission-factor computation model. The HFC model has been used in several policy tests for DOE to examine changes in vehicular fuel consumption over time. In general, it meets criteria 1 (for highway modes only), 2, 4, and 6-8 (Sec. 2.2).

Although the HFC model reports diesel share of VMT by mode for highway vehicles, the actual diesel fleet penetration by year, as well as annual new-vehicle registration (for entry into a vehicle-survival function), must be exogenously specified. The model has no true behavioral component; baseline relationships within the fleet are assumed to remain constant, and changes in household demographics or carrier economies of scale have no effect on them. Therefore, the model fails to meet criteria 1 (for off-highway vehicles), 3, and 7 (off-highway; also, the assumption that baseline relationships remain constant when subjected to the stimulus of new technologies is unrealistic).

2.3.3 State-Level Highway Gasoline and Truck Diesel Fuel Demand Models

Because the HGDM is launched directly from state-level gasoline-consumption data, it is the only model reviewed in this class for which state-level forecasts are directly obtainable. Both the highway gasoline and truck diesel fuel demand components allow for new-technology penetration (employing production theory and utility-maximization principles that assign different discount rates to each class of vehicle purchasers) and separate diesel share accounting. Automobile-ownership levels are sensitive to population density -- a desirable attribute for distinguishing urban from rural travel. An empirical vehicular scrappage/survival rate for each state or subregion, if available, may be applied to generate state-specific forecasts of fleet profiles.

Forecasts cover only highway modes. The model is policy-sensitive and focused at the household level; demand for used cars is accounted for separately from demand for new cars. Again, the HGDM forecasts the results of changes in fleet composition and activity from the extensively specified empirical baseline; it does not use a driver model to define the macroeconomic framework for its projections. The HGDM meets criteria 1 (highway vehicles only), 3,4 (at the state level), 5 (with limitations noted below), 7 and 8 (Sec. 2.2).

The HGDM does not model total travel by forecasting the demand for trips; instead, it calculates VMT from total fuel consumption and aggregate efficiency of highway modes. It does not treat air, rail, or waterborne freight. Its input data requirements are substantial (more than 14,000 individual records are required per forecast), but default values for most of them currently reside in ORNL and DOE software files. Households may select that mix of vehicles and available technology that best meets the constraints of their production functions, but the actual degree of maximum penetration of each new technology into the automobile and truck markets is prespecified. Thus, the HGDM fails to meet criteria 1 (off-highway), 2, 6 (because activity is merely extracted, not forecasted), and -- unless all defaults are used -- 5.

2.3.4 Transportation Energy Conservation Network Model

TECNET is the only model reviewed in this class of models that has a built-in procedure for computing the environmental residuals of vehicular operation. It uses the macroeconomic forecasting driver INFORUM to develop the input/output coefficients that generate future national transportation activity. All transport modes are considered, and travel is separately reported for local-passenger, intercity-passenger, and freight movement at the national level. The behavioristic paradigm of the Unified Mechanism of Travel (UMOT)* -- Zahavian time-budgets -- is the basis for the model's modal choice/mode split algorithm for allocating personal travel miles. The TECNET model has been deployed in several DOE environmental-policy analyses, generally in conjunction with the SEAS model.

The TECNET model thoroughly meets all Sec. 2.2 criteria except 5 and 7. It fails these only because of a very large requirement for exogenous data specification (including diesel share of fleet in each forecast year) and some rather simplistic assumptions concerning the truck fleet. For example, the light-truck share of the total vehicular (automobile and truck) fleet is computed as a constant multiple of automobile registrations for any year. Moreover, the operational and process energy requirements and emission-residuals factors used in the current version of the model are about four years out of date.

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*See Sec. 2.3.6 for a description of UMOT.

2.3.5 Transportation Energy and Emissions Modeling System

The components of TEEMS are as follows:

- A disaggregate personal-travel activity model to estimate all (local plus intercity) personal travel,
- A household vehicle-stock forecasting model to define the fleet composition of personal automobiles in future years,
- An SMSA-to-SMSA travel-demand model to determine that portion of personal travel occurring on trips greater than 100 miles in length,
- A freight activity-projection model disaggregated by mode of haul and commodity sector,
- An activity-regionalization algorithm, and
- An emissions-computation algorithm.

The TEEMS estimates future travel activity based on changes in baseline empirical relationships -- identified by the 1977 Nationwide Personal Transportation Study (NPTS),[7] the 1977 National Travel Survey (NTS),[8] the 1977 Commodity Transportation Study,[3] and the 1977 Truck Inventory and Use Survey (TIUS)[9] -- brought about by changes in economic conditions as forecasted by a driver model. The personal-travel components of TEEMS are household-based, while the freight-movement components are shipper- and commodity-based.

Model activity outputs are national VMT by on-highway modes, passenger-miles of travel by air and rail passenger modes, and ton-miles of travel by off-highway freight modes. The TEEMS computes energy requirements directly and is linked to the U.S. Environmental Protection Agency's (EPA's) MOBILE3 model and to off-highway and SO_2 factors for computation of air-pollutant emissions. The diesel share for automobiles is computed within TEEMS by a consumer-choice algorithm. A regionalization procedure to translate national transportation activity to the state level precludes the necessity for adapting the modeling system to process state-level input data (which would have been invalid in any case, because the empirical base consists of national data). Households may select holdings from (but are not *required* to obtain) new technology offerings that appear in future years; the characteristics of these advanced vehicles are provided in the consumer-choice model.

The various components of the TEEMS package have been applied to forecasting personal-vehicle fleet-mix and purchase patterns,[10] projecting freight volumes and mode splits during a petroleum shortfall,[11] estimating urban demographic shifts by household type and composition,[12] and investigating the relationship between commercial air-carrier financial yield and air passenger-miles of travel.[13] Sponsors have included the DOE Office of Vehicle and Engine Research and Development, Office of Environmental

Analyses, Office of Energy Contingency Planning, and Office of Energy Supply Transportation. The Economics Division of General Motors, Inc., has also used the personal-vehicle model in its size-class and technology-market-share projection activities. The Energy Information Administration (EIA) of DOE currently uses the TEEMS freight forecasting procedure in its fuel-demand projection model.

With the possible exception of criterion 4 (for off-highway modes), TEEMS meets all eight Sec. 2.2 criteria.

2.3.6 Sketch-Planning Models for Increased Specificity of Urban Activity

Some specific models, geared primarily to forecasting urban transportation activity at a sketch-planning level of resolution, are now to be considered. Despite good performance at the city or metropolitan regional scale, none appears readily adaptable for the generation of combined urban/rural transportation activity for statewide or national emissions inventories. This fact alone makes these models poor candidates for the test runs planned under Phase 1, but they are worthy of possible consideration, due to their greater detail, for later assessments.

Short-Range Generalized Transportation Policy Model (SRGP). The SRGP model includes a series of eight models (primarily of the multinomial logit form) calibrated at a disaggregate household level. The modeling package was developed for DOE by Cambridge Systematics, Inc., in 1978, specifically to evaluate the energy-conservation potential of a broad spectrum of transit, carpooling, vanpooling, parking, pricing, and other transportation-system management measures. The methodologies are based on sketch-planning in nature and context. The individual models are linked or related so that the results derived by lower-level models, such as those associated with nonwork trips, depend on the choices predicted by higher-level models, such as work-trip mode choice or automobile ownership. The models are implemented by a computer program that is compatible with the Urban Transportation Planning System (UTPS). An emission-computation procedure incorporating user-specified emission factors by 1-mi/h speed increments is embedded in the latest version of the SRGP model.

Transportation Resource Allocation Study (TRANS). This is a national policy-planning model design to produce quick-response, multicriteria evaluation of transportation options. In an earlier study by the U.S. Bureau of the Census, this model was applied to 64 regions with population greater than 500,000. A mode-split model is included, although there is no treatment of travel demand or supply characteristics outside of urban areas. The TRANS model, which operates at a relatively coarse level, has been used to assess the effect of up to 12 alternative levels and mixes of capital funds for highways and public transportation in the nation's largest urban areas. Four aspects of transportation (freeway, surface arterial, conventional bus, and rapid transit) are included. Travel projections are made on the basis of both socioeconomic variables and the nature and extent of transportation-system alternatives.

Transportation Integrated Modeling System (TRIMS). This approach was one of the earliest efforts to adapt the conventional small-zone travel-forecasting model system (trip generation, trip distribution, modal split, and traffic assignment) to a sketch-planning level of detail. Intended for application at an aggregation level of 100 to 150 zones/districts, TRIMS otherwise retains most of the characteristics of the conventional sequential model chain. A disutility form for the mode-choice model is used. The TRIMS model can be applied efficiently at regional, county/city, corridor, and sub-area levels. Processing of network data is required to derive transit and highway skim trees (minimum time paths). The TRIMS model was developed for the Metropolitan Washington Council of Governments.

Unified Mechanism of Travel (UMOT). Another innovative approach to analysis of travel demand, UMOT is a highly simplified, manually applied model based on a theory of consumer behavior. The model assumes that travelers attempt to maximize their spatial and economic opportunities, represented by total daily travel distance, subject to the constraints of travel cost and travel time. These constraints are not identical for all travelers, thus permitting stratified analysis by household income levels. Within this basic optimization approach, which maximizes average daily travel distances up to the constraint ceiling, travelers choose the number of trips, trip distances by trip purpose, mode shares, and automobile-ownership levels. Varying the time and cost-model characteristics allows testing of alternative transportation-control/transportation-systems-management strategies that affect these characteristics. (The UMOT model is cited here because it forms the basis of the mode-split computation algorithm in TECNET.)

2.4 RECOMMENDATION FOR MODEL SELECTION

All models reviewed have merits and capabilities relevant to providing forecasts of transportation activity appropriate to the Phase 1 test runs, but none is complete with respect to the configuration contained in the TG-B specification document.[14] That is, no one model is currently capable of forecasting both transportation activity and emissions for all relevant modes of travel. The two models that come closest to meeting all the important criteria (listed in Sec. 2.2) are TECNET and TEEMS. Each model would require additional manipulation before it could become operational for the test runs planned under Phase 1: residuals-computation factors, as well as technology assumptions implicit in TECNET, must be updated, and a better means must be found to account for truck growth. A way to link TEEMS off-highway activity results to relevant emission factors would have to be developed. Both models should be verified (through calibration to a baseline state-level inventory) at subnational levels.

Given these considerations, it is believed that TEEMS is better suited for inclusion in the TG-B emissions model set. The currency of forecasting assumptions in TEEMS and the relative ease and low cost with which emissions computation and state-level allocation procedures can be added to enhance the modeling package speak very strongly in its favor. Accordingly, TEEMS is recommended as the modeling system to forecast transportation activity and emissions in the TG-B emissions model set for the Phase 1 test runs.

3 STRUCTURE OF THE TRANSPORTATION-ACTIVITY MODULES IN TEEMS

The Transportation Energy and Emissions Modeling System employs its four activity-forecasting modules (see Sec. 2.3.5) in three modeling streams to develop national estimates of the following quantities:

- Long-distance passenger travel,
- Local passenger travel, and
- Movement of goods.

Figure 3 presents an overview of the TEEMS process, while Fig. 4 elaborates on the structure of each of the three modeling streams identified above.

In Sec. 3.1, each of the four activity modules, together with how each contributes to one or more modeling streams, is briefly described. This is followed by a detailed discussion of each module: its purpose, input and output flow, and resolution.

3.1 MODEL COMPONENTS

3.1.1 Disaggregate Personal Transportation Activity Module

The Disaggregate Personal Transportation Activity Module (DPTAM) generates VMT values resulting from all local and intercity personal travel. Its empirical basis is the NPTS.[7] This module characterizes households by demographic and economic characteristics. The cells present in the household-characteristic matrix (a total of 6,912) are partitioned as follows: geographic location (two levels -- urban/rural), income (three levels), household size (four levels), education of head (four levels), number of workers (four levels), age of head (six levels), and vehicle ownership (three levels). It is assumed in DPTAM that VMT/household within a cell will be elastic only with respect to the per-mile operating cost. In its present form, DPTAM uses one value of elasticity for all households. It could use multiple elasticities if they were available.

However, the change from *baseline* travel characteristics of each cell will be identical across geographic regions, because the national survey from which these characteristics were extracted does not permit identification of variations in cell behavior by state or region.

3.1.2 Disaggregate Vehicle Stock Allocation Module

The Disaggregate Vehicle Stock Allocation Module (DVSAM) allocates vehicle ownership to households. Its empirical basis is the NPTS, the same as for DPTAM.[7] The number of household cells is collapsed to 576. The model does not use the number-of-workers parameter or geographic location, as does DPTAM, and DVSAM also ignores households without vehicles.

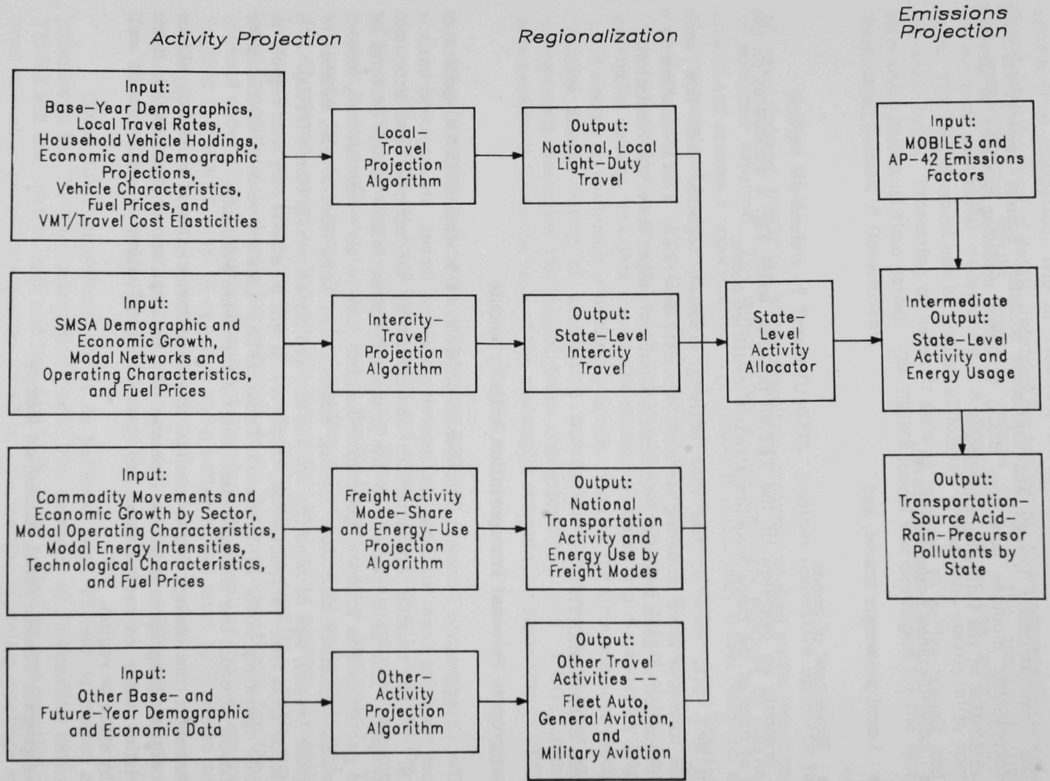


FIGURE 3 TEEMS Process and Modules

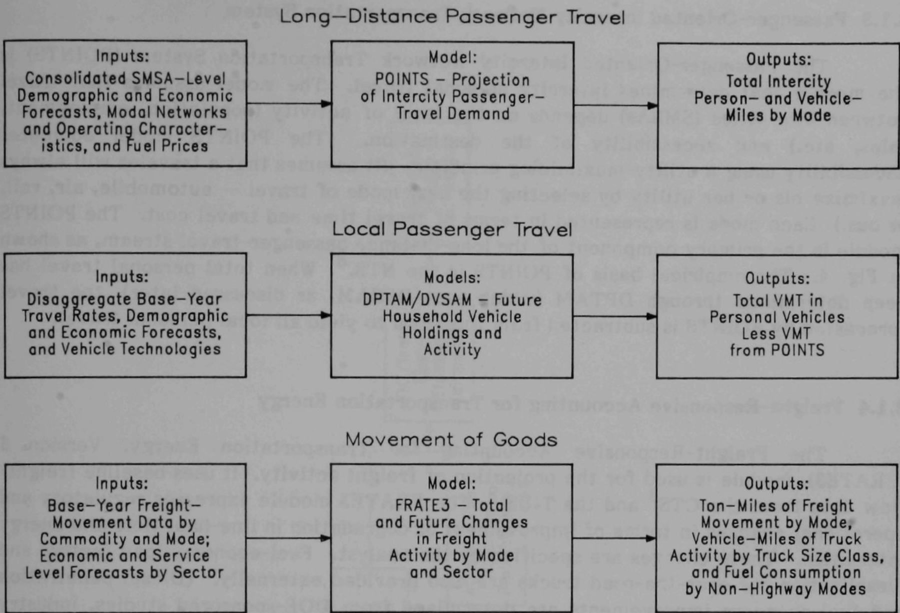


FIGURE 4 Streams Associated with TEEMS

The DVSAM model selects from a menu of up to 10 vehicles. These would include conventional (Otto or diesel) vehicles operating on either conventional petroleum or alternative fuels, as well as conventional vehicles characterized as having advanced engine material components (such as high-temperature ceramics). Forecasts include the opportunity for penetration of alternative advanced heat-engine vehicles powered by the Stirling cycle or the Brayton (gas-turbine) engine after 1995. Expected performance levels of different sizes/technologies and their age distributions are reflected in the vehicle menu.

Although individual households have the freedom to move from one demographic cell to another over time, the average automobile-ownership characteristics of each cell are frozen through time. Thus, for example, if one or more actual households in a cell for which the average vehicle ownership was 2.3 cars should choose not to own a car, this fact could not be detected within the model. However, the model *is* sensitive to the restraints on actual driving, imposed by high vehicle-operating costs, that a household in this cell would experience.

3.1.3 Passenger-Oriented Intercity Network Transportation System

The Passenger-Oriented Intercity Network Transportation System (POINTS) is the module that determines intercity personal travel. The model assumes that travel between two cities (SMSAs) depends on the level of activity (population, employment, sales, etc.) and accessibility of the destination. The POINTS model computes accessibility using a utility-maximizing principle. (It assumes that a traveler will always maximize his or her utility by selecting the best mode of travel -- automobile, air, rail, or bus.) Each mode is represented in terms of travel time and travel cost. The POINTS module is the primary component of the long-distance passenger-travel stream, as shown in Fig. 4. The empirical basis of POINTS is the NTS.[8] When total personal travel has been determined through DPTAM (which uses DVSAM, as discussed later), the travel forecasted by POINTS is subtracted from this total to yield all local personal travel.

3.1.4 Freight-Responsive Accounting for Transportation Energy

The Freight-Responsive Accounting for Transportation Energy, Version 3 (FRATE3), module is used for the projection of freight activity. It uses baseline freight-flow data from the CTS[3] and the TIUS.[9] The FRATE3 module expresses regulatory and operational changes in terms of improvement or degradation in line-haul time and energy intensities. These changes are specified by the analyst. Fuel-economy load factors and dieselization for over-the-road trucks are also provided externally. (Diesel penetration and fuel-economy improvements are determined from DOE-sponsored studies, industry and trade-association reports or personal contacts, and scenario-specific technology-penetration goals.) This procedure has been updated to account for post-1980 changes in regulations, modal performance, service characteristics, and fuel prices and to specify truck activity with greater precision. The FRATE3 module, of which the National Freight Demand Model (NAFDEM), a shipper-mode-choice model (see Sec. 3.5) is a submodule, constitutes the goods-movement modeling stream of TEEMS (Fig. 4).

3.1.5 Summary

The previous discussion has outlined the major components of TEEMS; a more detailed presentation of the logical flow of all three streams of TEEMS may be found in Ref. 15 (p. 20). The following subsections focus on the flow and procedures of TEEMS by component model for each of the three modeling streams: long-distance passenger travel, local passenger travel, and movement of goods.

3.2 DETAILED DISCUSSION OF COMPONENT MODELS

3.2.1 Disaggregate Personal Transportation Activity Module

The structure of DPTAM is shown in Fig. 5. The purpose of DPTAM is to estimate future total personal vehicular travel. This estimate is based on the effect of

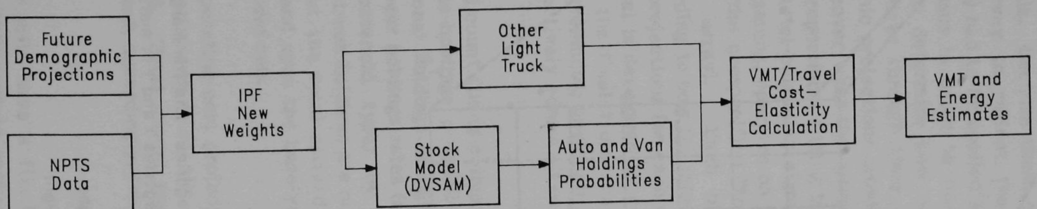
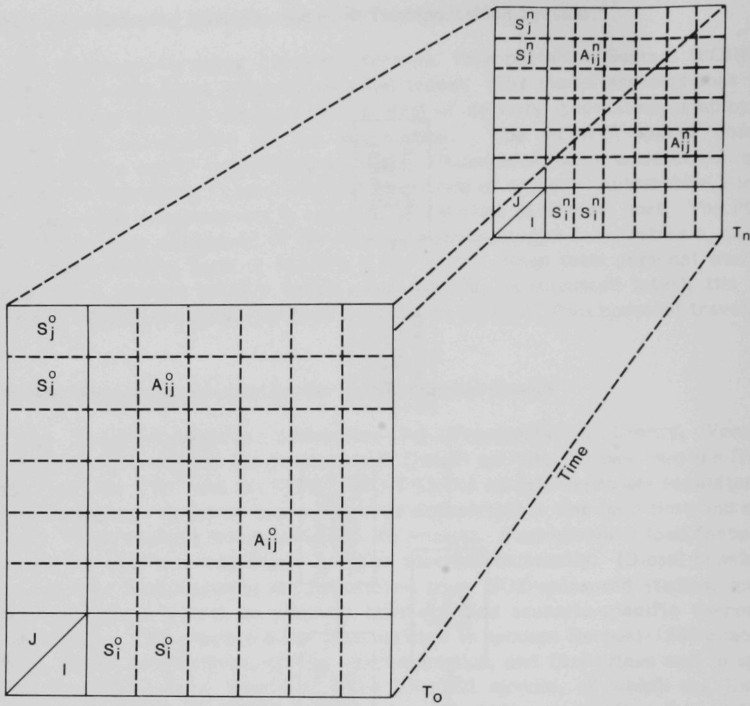


FIGURE 5 Structure of DPTAM



$$A_{ij}^n = S_j^n / S_j^o \ A_{ij}^o$$

$$A_{ij}^n = S_i^n / S_i^o \ A_{ij}^o$$

$$W_{ij}^n = A_{ij}^n / A_{ij}^o \ W_{ij}^o$$

where:

A_{ij}^o = Original cell total

$S_i^n S_j^n$ = Target margins for categories i and j in margins I and J

$S_i^o S_j^o$ = Sample margins for categories i and j in margins I and J

A_{ij}^n = Forecast cell total

W_{ij}^o = Original household weight

W_{ij}^n = Forecast household weight

FIGURE 6 The Method of Iterative Proportional Fitting

changes, from an empirical baseline, in values of the variables in a household's decision about how much to travel. The modeling procedure is as follows:

1. The NPTS provides baseline counts of households in each of the 6,912 descriptor cells. Because these counts have been expanded from a sample survey to reflect the national totals in 1977, weights (multipliers) had to be applied to survey totals by the U.S. Bureau of the Census in order to produce the desired national totals. In order to determine how cell totals will expand and redistribute themselves through time while remaining consistent with the demographic projections provided by the driver model, it is necessary to discover what the future cell weights will be. For this, an iterative proportional fitting technique (Fig. 6), similar to most row/column total-balancing algorithms used in applications for business and planning, operates on the base-year weights using forecast margins (the prespecified "row" and "column" totals for the 7-dimensional array). Each of the 6,912 base cells is "reweighted" according to how the margins (row and column totals) are distributed in projections for each of the individual categories, and a new cell total is developed by convergence of the iteration procedure. Thus, the final 7-dimensional array has all row and column totals in agreement; each cell is factored by a new weight, which -- used collectively across all cells -- makes such agreement possible.

2. The new household count file is collapsed to 576 cells for selection of personal-vehicle-holdings probability vectors by DVSAM (see Sec. 3.2.2). Personal holdings of light trucks are determined by multiplying base-year holdings rates (average number of trucks per household, by household type) by the new cell counts and summing. Future truck holdings are not necessarily proportional to those for cars, but the total arrived at through this categorical analysis does depend upon the base-year values for average truck holdings by household cell.

3. Fuel and other operating-cost projections* are applied to travel-cost elasticity estimates from the literature (see Ref. 15 for specific citations). Total annual travel by household is adjusted upward or downward, accordingly, from the baseline.

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*Vehicle operating costs per mile have a fixed (exogenously specified) and variable (endogenously determined) component in each vehicle-characterization vector -- see below, Sec. 3.2.2. The fixed component represents a proration of out-of-pocket lubrication, repair, and maintenance costs over the expected life of the given vehicle. The variable component depends on fuel cost (¢/gal), together with the fuel efficiency (consumption rate in gal/mi) of the given vehicle.

4. Output is total personal trips and travel miles by vehicle size class and technology, which translates to total gallons of gasoline and diesel fuel consumed (through the fleet-weighted fuel economy computed in DVSAM) and to total emissions (through MOBILE3).

The DPTAM is the most straightforward and least complex of the four activity models of TEEMS. It is completely reliant on the accuracy of the base-year (cross-sectional) survey in defining the initial mix of demographics nationally. That is, if the base-year survey has significantly over- or underrepresented certain cell types, changes in the population of these types over time will be different from those generated in Step 1 of DPTAM, even if the corresponding Census forecast is 100% correct. Moreover, survey confidentiality precludes identification of respondents by state of residence on the NPTS public-use tapes; even if such identification were possible, the small sample size would make assignment of cell weights by state very unreliable. For this reason, *direct* subnational application is infeasible. The DPTAM can be applied at the national level to any year for which forecasts of household totals and "margins" have been defined.

3.2.2 Disaggregate Vehicle Stock Allocation Module

The structure of DVSAM is shown in Fig. 7. The model's greatest significance, from the standpoint of emissions computation, is that it provides an endogenous procedure for estimating future fuel-type shares within the stock of personal light-duty automobiles and vans. After VMT by fuel share has been determined by summing over each vehicle size/technology category, fuel-specific emission factors can be assigned to the appropriate quantity of personal travel.

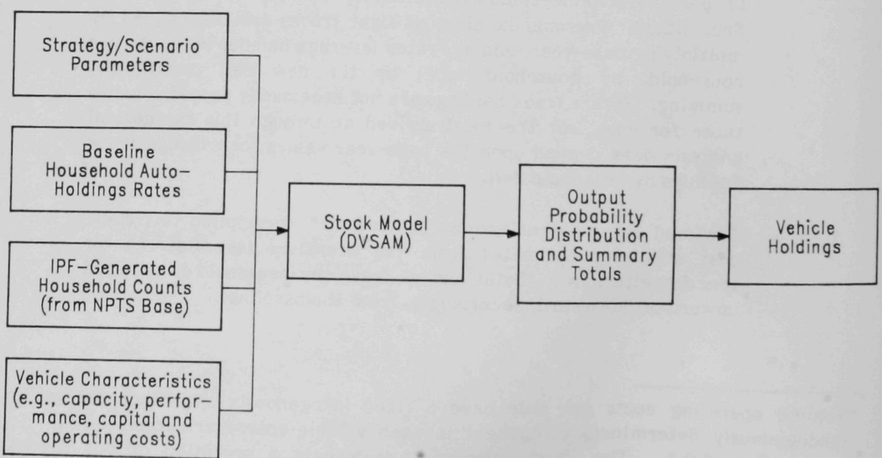

FIGURE 7 Input and Output File Structure of DVSAM

The DVSAM module is based on the Lave-Train vehicle choice model, using all variables and nondummy coefficients of that formulation.[16] Bias coefficients for each vehicle type were calibrated to the base-year (NPTS) distribution. The modeling procedure is as follows:

1. An engineering algorithm developed for the purpose of "building" future automobiles from the ground up[17] is deployed to produce a set or sets of vehicle characteristics (by size and mission of vehicle) consistent with the technological thrust or success of the scenario to be analyzed. A bill of materials is defined for each vehicle (weight composition of mild and lightweight steels, alloys, composites, ceramics, and other high-strength low-weight substances), a target performance (power-to-weight ratio) is defined, and the automobile is "built" to specifications. The algorithm takes into account curb weight, coefficient of drag, and fuel flow at idle, cruise, and acceleration/deceleration. The values of all variables must converge to a logical, internally consistent set of descriptors. The key descriptors needed by DVSAM are purchase cost (fabrication cost, plus markup and interest charges, in new-car sales mode only), operating cost in cents per mile (as described in Sec. 3.2), seating capacity (2,4,5,6, or 9 passengers), curb weight, and horsepower.

2. A file of up to 10 vehicle-characterization vectors interacts with the relevant household-descriptor variables for each forecast year. On the basis of the interaction between demographic and technology-related variables in the Lave-Train approach, each household cell will have its own utility computation with respect to the vehicle offerings.

3. The computed utility function of each vehicle for each household is summed together with the other vehicle utilities to that household; the exponential ratio of each utility function to that sum (using the standard logit formula) represents the probability that the vehicle will be selected as a new car. However, because it is the changes in household holdings patterns over time that are of interest, one takes the ratio of the change in utility of a given vehicle type between the base and forecast years to the sum of utility changes, again expressed in the logit formula.

4. Household probability vectors are created (row-wise) by computing a holdings distribution for each cell, with each household's probability row summing to one. If a new-technology vehicle not available to households in the base year has been introduced prior to the forecast year, its probability of being held is equal to its absolute utility (see item 2, above), and the residual probability share is then allocated to the existing-technology cars.

5. Each distribution is multiplied by the forecasted number of households in each cell, and a column sum (over vehicles) is computed to determine total vehicles (and shares) by size and technology. In DPTAM, each household unit is operated on independently (through the elasticity function) to determine how much that household will travel and in what cars.

The DVSAM module is operable on any population sample, but the only reliable data base currently available to the model is the NPTS, from which state-specific baseline holdings distributions cannot be extracted.

3.2.3 Passenger-Oriented Intercity Network Transportation System

The most useful feature of POINTS is that its output has recently been linked to an actual model of the U.S. surface transportation network, which permits each SMSA-to-SMSA trip to be partitioned according to the state(s) through which the trip passes; an appropriate mileage total can be directly allocated to each intervening state as the trip is dispatched. Again, column sums over the product of all vector components (49 zero and nonzero fractions per vector) and the respective trip total times miles for each vector yield a direct estimate of miles of travel for trips greater than 100 miles, by state.

The procedure shown in Fig. 8 may be described as follows:

1. Detailed modeling is applied to city pairs to estimate SMSA-to-SMSA passenger-miles of travel (PMT) by trip purpose and mode. This is the time- and cost-dependent disutility-minimizing approach to direct estimation of modal demand.

2. Growth rates are determined by the magnitude of changes in values of the explanatory variables projected from the 1977 base year to each forecast year for SMSA-to-SMSA PMT by mode, using the results from Step 1.

3. The growth rates (Step 2) are applied to 1977 estimates of intercity PMT, defined as all trips $\geq$100 mi one way, to estimate future-year intercity PMT by mode.

4. Vehicle load factors are applied to convert automobile, light-truck, and bus PMT to VMT, air PMT to LTO cycles, and rail PMT to total fuel consumed.

5. VMT- or fuel-based emission factors are applied to convert outputs to total emissions by mode.

Because DPTAM forecasts *all* personal travel (both local and intercity), it is necessary to subtract the total miles estimated in POINTS from total passenger miles computed in

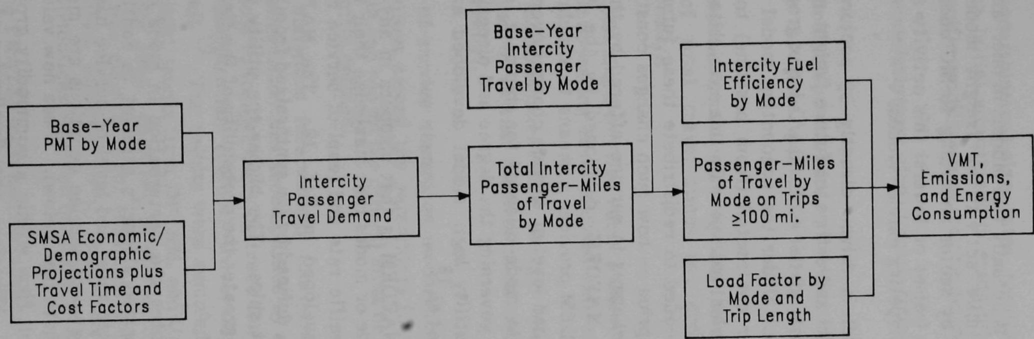

FIGURE 8 POINTS Input Requirements and Post-POINTS Processing

DPTAM in order to obtain final results for the local passenger-travel stream (total personal miles of local travel on trips of less than 100 miles).

3.2.4 Freight-Responsive Accounting for Transportation Energy

The FRATE3 module is actually two models in one: an accounting procedure that directly indexes future ton-mile activity by freight mode to base year totals and forecasted economic growth by sector according to SIC code, and a mode-share model that distributes and controls (raises or lowers) this activity according to fuel price and level of service offered by competing carrier modes.

The accounting model is driven directly by sectoral results of an economic input/output forecasting model and estimates future freight-movement activity by mode and sector, largely on the basis of the sectoral I/O index growth for 20 principal groups at the 2-digit SIC code level. Under the accounting model alone, future mode shares (percent) of the expanded or contracted (from baseline) total of ton-miles would be identical to those of the empirical base year (in this case, data from the CTS).[3]

A second model is needed to redistribute these future shares in a way that is sensitive to changes in fuel price -- how such changes constrain certain carrier modes more than others -- and to changes in service offered by the transportation sector at large. One such model is NAFDEM, developed by the Massachusetts Institute of Technology (MIT). The NAFDEM provides a means to simulate shipper response to and the aggregate effect of rate and level of service changes over time. This response could involve a change in the freight mode selected for shipment, a change in the size of the shipment, or both. The logic governing the degree and direction of change arises from a freight-mode/shipment-size utility logit model developed and calibrated to observed shipment behavior by Chiang et al.[18]

A basic premise of NAFDEM is that shippers in any commodity group seek to move more freight by the mode or modes that maximize their total utility. This utility is computed from the mode-specific rate and level-of-service relationships to commodity characteristics that were developed in Ref. 18. The NAFDEM constructs a utility function for a simulated firm, defined by (or synthesized from) the characteristics of and demand for the commodity it ships. The higher the utility of a given mode to a firm simulated in this manner, the greater the probability of the firm's shipping its commodity by that mode.

The NAFDEM calculates the perturbation in mode choice and shipment sizes brought about by each synthesized shipper's attempt to continue to maximize its total utility after a change in carrier rates and level-of-service has been defined. Computed values of the MIT rate and level-of-service equations are modified by changes in fuel cost, service parameters, or both (see below). These new values will in turn change the computed "perception" of each firm within a commodity group as to which mode best suits the firm's overall needs. Therefore, the distribution of probable modal choices is recalculated from the utility function for each shipper, considered according to the revised rates and service levels. The total change in each predicted probability over the respective baseline value determines mode and shipment-size redistribution.

In its current form, the NAFDEM can evaluate scenarios that affect the following:

1. Changes in fuel cost, in constant dollars (defined externally);

2. Changes in mode/shipment-size rates resulting from increasing fuel prices (the initial adjustment is made internal to the model, but carrier-specific modifications may be defined externally);

3. Changes in mode/shipment-size travel times, in days (defined externally);

4. Changes in mode/shipment-size reliability of delivery within a given number of days past the mean travel time (defined externally);

5. Changes in mode/shipment-size waiting times, which are those components of total travel times not including the line-haul (defined externally);

6. Changes in mode/shipment-size rates induced by modifications to nonfuel carrier operating costs (defined externally); and

7. Changes in mode/shipment-size energy intensity, measured in average number of British thermal units consumed per ton-mile (defined externally).

Only the effect of level-of-service change on mode/shipment-size choice is computed within the model; interactions among the parameters listed in items 2 through 6 above (the effect that a change in one has on the others) must be estimated prior to preparation of the input file and explicitly defined.

For on-highway emissions forecasting, ton-miles of haul by truck must be converted to VMT. This conversion was accomplished by applying sector- or commodity-specific average load factors to freight-carrying truck ton-mile estimates and calibrating to Federal Highway Administration (FHWA) travel-mile data from the publication *Highway Statistics* (annual).[19] The results were summed together with VMT estimates for personal (nonfreight) light trucks from DPTAM, and the resulting total was within 5% of published FHWA data for 1980. Each cell in the vector of VMT by commodity sector has been split into four size classes: light (manufacturers' gross vehicle weight [GVW] classes 1 and 2A), medium (classes 2B-5), light-heavy (class 6), and heavy-heavy (classes 7-8), based on distributions obtained from the 1977 TIUS.[9]

Figure 9 shows the FRATE3 logic and its outputs.

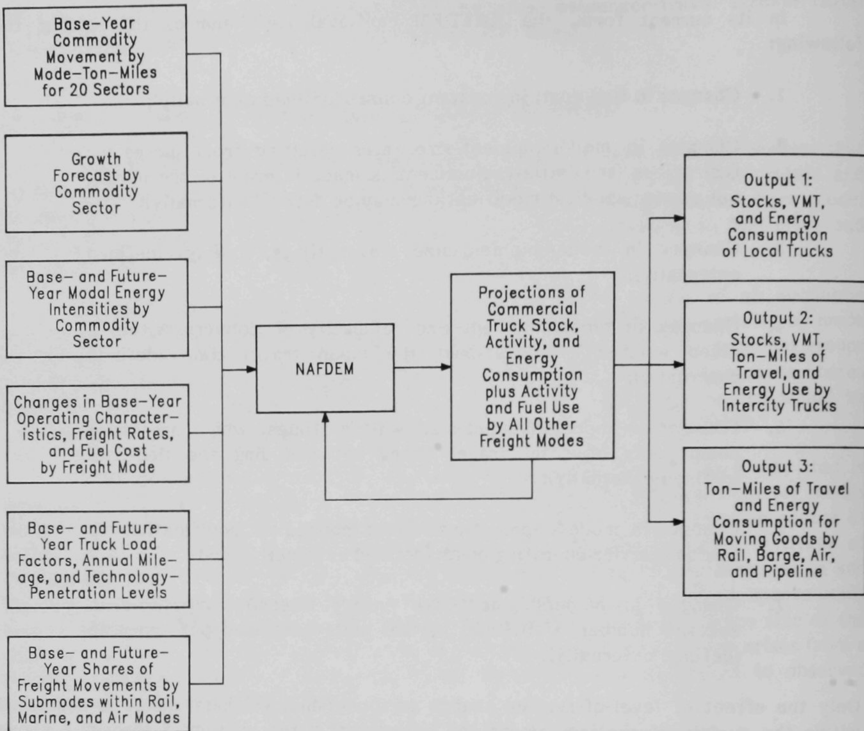

FIGURE 9 FRATE3 Flow and Outputs

3.3 OTHER ACTIVITIES MODELED AND NOT MODELED

The TEEMS also computes activity by private and rental-fleet automobiles, as well as by general and international aviation. Activity in both areas is forecasted by categorical analysis (growth from baseline) for important specific indicators (see Sec. 3.4). A schematic of the fleet auto procedure is shown in Fig. 10. Internal-combustion-engine activities *not* included are as follows:

- Off-highway construction and industrial and agricultural vehicle operation on either gasoline or diesel fuel;
- Recreational vehicle operation off-road, such as boating, cross-country motorcycling, or ski-mobiling; and
- Operation of light-duty lawn and garden equipment.

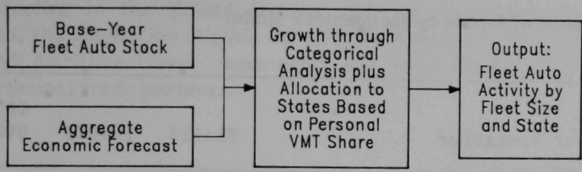

FIGURE 10 Forecasting Procedure for Fleet Auto Activity

3.4 INPUT REQUIREMENTS AND OUTPUTS OF TEEMS

The TEEMS requires demographic, economic, and technological inputs to project transportation activities. It uses household-related variables and future vehicle technology projections to produce personal-travel estimates, and it also uses economic variables -- together with projected operating characteristics of freight modes -- to produce freight-activity estimates. The intercity-travel component of TEEMS requires SMSA-level economic and demographic information. With the exception of this intercity-travel component, all components use national data values and produce national estimates, which are then assigned to states through the regionalization component. Outputs of all TEEMS components in terms of VMT, ton-miles of travel (TMT), or fuel consumption, together with such other inputs as speeds, vehicle-age distribution, climatic conditions, and driving-cycle stages, are required by the emissions module (described in Sec. 4) to produce estimates of pollutants emitted.

Table 2 provides a checklist of data required by the TEEMS. The table does not include the data required by the emissions module, since most of the data not produced by TEEMS itself are required only by EPA's MOBILE3 model.

The personal-travel component (DPTAM) uses mostly demographic data. It uses personal income and fuel prices among the economic variables listed in Table 2. The fuel prices are used in part to construct vehicle-characteristics menus for the vehicle-stock allocation model (DVSAM, described in Sec. 3.2.2) and to compute changes in cost per mile for the elasticity function. The personal-income variable is used to compute percentages of households in low-, medium-, or upper-income categories.

The intercity-travel component (POINTS) uses gross national product (GNP), employment, hotel/motel share of service-sector output, fuel prices, and population data. The POINTS model requires all inputs by SMSA.

The freight component (FRATE3) uses economic activity, industrial-production indexes, employment in service sectors, production-growth projections in other sectors, and fuel prices. Inputs to the freight component are by 20 major commodity sectors. The growth projections or indexes are used to develop scenario-specific freight-activity growth.

Table 2 also lists inputs for models classified as "other." These models include general aviation, automobile fleets, and portions of international air and maritime travel

TABLE 2 Checklist of Inputs by Component Model

Input Variables	FRATE3	POINTS	DPTAM/ DVSAM	Other
Demographic variables				
Total population		x		
Total households			x	
Household demographics			x	
Population >18 yr				x
Economic variables				
Gross national product	x	x		x
Industrial production index	x			
Production indexes by commodity sector	x			
Volume of agricultural exports	x			
Total employment		x		
Employment in government sector		x		
Employment in services, trade, wholesale/retail, and construction	x			
Hotel/motel share of service-sector output		x		
Personal income			x	
Disposable personal income				x
Fuel prices	x	x	x	x
Economic growth among principal trade partners				x
Technological variables				
Auto and van characteristics			x	
Compact/full-size light-truck shares	x		x	
Truck diesel shares	x			
Commercial-truck VMT shares	x			
Truck load factors	x			
Marine-area (waterway) shares	x			
Passenger aircraft load factor(s)		x		
All-cargo air-freight share	x			
Air carrier yield		x		
Energy intensities by mode	x	x	x	x

that involve refueling in the United States. The general aviation component uses disposable income, the population eligible for pilot licensing, and price trends. The international air- and maritime-travel components use price trends, GNP, and economic growth among principal trade partners.

4 STRUCTURE OF THE EMISSIONS-FORECASTING MODEL IN TEEMS: RECOMMENDED COMPONENTS FOR THE 1985 TEST RUNS

This section presents a framework for transportation emissions modeling in the test runs planned for Phase 1. Through this framework, EPA's philosophy and method of estimating transportation source emissions of acid-rain precursor pollutants -- SO_2, VOCs, and NO_x -- have been incorporated. The components of the recommended emissions model and the additional steps taken to enhance the model for service in the Phase 1 test runs are described in this context.

4.1 FRAMEWORK OF THE RECOMMENDED EMISSIONS MODEL

The MOBILE3 component, discussed in greater detail in Sec. 4.3, models only highway emissions of VOCs and NO_x, two of the three "Set II" criteria pollutants from on-road transportation sources (the other being carbon monoxide). Moreover, explicit emission-factor-computation options in MOBILE3 are available only through the year 2020, 10 years short of the final forecast year for the 1985 assessment. The EPA's AP-42 documents[20,21] contain emission factors for off-road transportation source activity, as well as SO_2 emission factors (in g/mi) for highway vehicular travel. Both sources of data (MOBILE3 and AP-42) are required. Together, the two components appear to constitute the best arrangement that can be devised within the constraints of Phase 1 criteria. Moreover, because EPA models and emission factors were used in the preparation of the 1980 baseline inventory, consistency with that approach should be retained in the forecasting process and in the effort to replicate the 1980 inventory using TEEMS activity outputs (see Sec. 7).

4.2 EPA APPROACH TO MOBILE-SOURCE MODELING

On the basis of years of research, the EPA has concluded that emission rates of the Set II pollutants (VOCs, NO_x, and CO) by highway transportation sources will differ for a given vehicle type according to such variables as ambient temperature and humidity, average speed of operation, and the state of the vehicle's engine (e.g., whether it has just started up cold). Accordingly, MOBILE3 and its predecessors (MOBILE1, in use between 1978 and 1981, and MOBILE2, in use from 1981 to 1984) have incorporated procedures for the modification of the basic "average" vehicular emission rate -- based on the federal test procedures (FTP) for new vehicles and the expected degree of emission-control deterioration that occurs as a vehicle ages -- according to user-stipulated values of these key variables. Thus, for example, a heavy-duty gasoline truck operating at 15 mph under ambient conditions appropriate to Minneapolis, Minnesota, in the winter will emit VOCs at a higher rate per mile than the same type of truck of the same age operating at the same speed in Tampa, Florida, in June. The MOBILE models reflect this difference. The models also can update the basic FTP emission rates to reflect statutory implementation of more stringent vehicle emission-control standards. Thus, the emission rate for each city as given by the MOBILE models will be far different in 2000 than in 1980.

4.3 COMPARISON OF MOBILE3 WITH MOBILE2

4.3.1 General Differences between Algorithms

In July 1984, the EPA released tapes of MOBILE3, the latest version of its mobile-source emission-factor computation algorithm,[22] on a limited-distribution basis for use in transportation emissions forecasting and planning applications. The model is now generally available and is specifically recommended by EPA over prior MOBILE models. The MOBILE3 model retains the general structure, basic input requirements, and formatting of its 1981 predecessor, MOBILE2,[23,24] which was initially used in preparing the 1980 NAPAP inventory. However, the revised zero-mile emission rates and deterioration factors (increase in emission rate as a vehicle ages) are now derived from a considerably larger body of data on initial and life-cycle performance of vehicles equipped with modern emission-control technology (e.g., three-way catalysts). This difference is most significant for the purpose of generating reliable forecasts of emissions performance of vehicles on the road, and it is the single most important reason for using MOBILE3 in the 1985 highway forecasts.

In addition to providing (for the first time) emission-reduction credits for anti-tampering programs, MOBILE3 retains the most useful features of its predecessor models with respect to scenario testing. These features, which could play a major role in the control scenario testing of future assessments, include the following:

- Disaggregation of nonmethane and evaporative hydrocarbon emissions from total VOC rates, if requested;

- Calculation of inspection/maintenance (I/M) program emission-reduction credits;

- Modification of the default percentage of vehicle-miles operated in the cold-start mode (useful for truck operation, or if average speeds increase); and

- Acceptance of user-specified zero-mile emission rates and deterioration rates (e.g., for advanced-technology vehicles).

4.3.2 MOBILE3 Departures from MOBILE2 Relevant to the 1985 Test Runs

Three differences between the approach of MOBILE3 and those of its predecessors are important in the context of the Phase 1 test runs. These differences are associated with the data base, with truck operations, and with NO_x emission standards.

A problem common to virtually all emission-computation algorithms that rely on empirical test data covering past model years is that some or all of their components are out of date almost before the algorithms are made generally available. This obsolescence was essentially the fate of MOBILE2 (as it was, for somewhat different reasons, for the still earlier MOBILE1). Shortly after its release, MOBILE2 was attacked by the motor-vehicle industry as being unrepresentative of both present and future trends in vehicular emissions.[25] Moreover, the data blocks for future zero-mile emission rates were based on exhaust-emission standards for certain vehicle classes (particularly heavy trucks) that the industry contended could not be met without intolerable sacrifices in fuel economy and performance. The EPA attempted to respond to the industry's concerns by developing better, more current data and using these data to revise some of its base emission factors. These revisions, published in Ref. 24, came to be known as "MOBILE2.5" (although no model ever received this designation officially). However, doubt remained as to whether the revisions were the product of any detailed reexamination of the degree of deterioration in CO and NO_x emissions experienced by vehicles with advanced computerized engine-combustion-control technology, or whether the revisions accounted for the known tradeoff among NO_x, VOC, and particulate-matter emission control in heavy-duty diesel vehicles.

The MOBILE3 model, which devotes more attention to overall emission deterioration and heavy-duty diesel emission control than did MOBILE2, takes into account the fact that different classes of advanced combustion/emissions-control systems (such as throttle-body injection for controlled burn vs. standard carburetion) have different failure modes and give rise to different rates of emission deterioration. Deterioration rates coded in MOBILE3 reflect the likely mix of combustion- and exhaust-control technologies emerging in the 1980s and into the 1990s. Moreover, the effects of tampering on these systems, reflected for the first time by nationally estimated offsets added to the basic "untampered" emission rates, may be reduced by credits for antitampering programs that vary by the component(s) covered. There appears to be a greater recognition implicit in MOBILE3 that good fuel economy and good emissions performance are inextricably linked in the vehicles of today and tomorrow.

The MOBILE3 model takes steps toward accounting for the different daily operating conditions (duty cycles) experienced by different weight classes of heavy-duty trucks. The model provides an annual mileage accrual rate (by vehicle age) for each of four different heavy-duty diesel gross-weight classes (2B, 3-5, 6, and 7-8) in the data blocks. A new subroutine weights these accrual distributions together by the registration fractions of each vehicle-class category in each calendar year of interest (1980 to 2020).* This enables a user to account for different rates of aging by heavy truck classes, an important feature that was unavailable in earlier MOBILE models. In general, the heavier the truck, the longer the average full-service life.

The MOBILE3 model, as modified pursuant to guidance provided by the EPA Motor Vehicle Emission Laboratory late in 1985, assumes a final emission standard of 5.0 grams per brake-horsepower-hour (g/bhp·h) for heavy-duty diesel NO_x in 1991. This value is consistent with the final rulemaking of March 15, 1985 (50 FR 10606) and is certainly more accurate than the standard assumed in MOBILE2 (1.7 g/bhp·h, effective in 1985). As revised, MOBILE3 also includes zero-mile emission and deterioration rates for light-duty trucks appropriate to the standards of 50 FR 10606.

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*An option for extension to 2030 is discussed in Sec. 4.5.1.

In summary, MOBILE3 appears to be clearly superior to MOBILE2 with respect to the needs and focus of the Phase 1 test runs. However, the MOBILE3 model itself might well become obsolete prior to the preparation of (presumably more refined) emissions forecasts after 1985.

4.4 DEPLOYMENT OF EMISSION MODEL COMPONENTS

This section discusses, in general, how the two emission-modeling components of TEEMS are used in developing emissions inventories. The MOBILE3 component is to be used for developing VOC and NO_x totals for on-road vehicular activity, while the AP-42 factors[20,21] are to be used for developing VOC and NO_x totals for off-road transportation activity and SO_2 totals for all transportation activity. These components require enhancements to render them fully compatible with the needs and objectives of the Phase 1 test runs and to meet operability conditions. The required enhancements are discussed in Sec. 4.5.

4.4.1 MOBILE3: Structure and Capabilities

Mobile-source emission rates are difficult to estimate, because they vary by vehicular speed, ambient temperature, time from engine start-up, humidity, and even auxiliary-equipment load on the engine. A detailed model is required to account for all these sources of variation.

The MOBILE3 algorithms compute an emission rate (in grams per mile of travel) for CO, hydrocarbons (HC), NO_x, or all three from any of the eight principal vehicular types* involved in on-road travel.‡ The computation procedure can accept virtually any feasible combination of input speed, ambient temperature, stage of driving cycle (cold transient, hot transient, or hot stabilized engine temperature), humidity, and control strategy that defines the average operating conditions. The model generates both individual (by vehicle type) and composite (based on vehicle mix) emission factors representing exhaust emissions plus weighted hot-soak and diurnal fuel evaporation. Emission rates for the proportion of total HC emissions consisting of nonmethane (largely volatile) organic compounds may be reported separately. In any given input stream, different scenario conditions may be defined, and a separate set of factors will be generated for each scenario. This enables simultaneous computation for testing of multiple forecast years, including any projected change(s) over time in VMT share by vehicular type, in average operating speed by vehicular type, or in basic (user-specified) exhaust-emission rate that could result from a technology-penetration forecast or

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*Light-duty vehicles (LDVs; automobiles), light-duty trucks (LDTs) up to 8500 lb GVW, and heavy-duty trucks and buses (greater than 8500 lb GVW), all fueled by either gasoline or diesel fuel (3 vehicles x 2 fuels), plus motorcycles. In addition, the gasoline-powered LDT class is further subdivided into LDGT1 (less than 6000 lb GVW) and LDGT2 (6001-8500 lb GVW).

‡See Sec. 4.4.2 for a discussion of SO_2 and off-road emissions categories.

emission-control strategy. A more detailed presentation of this model is contained in Ref. 22.

Figure 11, extracted from Ref. 22, presents the hierarchical structure of MOBILE3. The MAIN program calls six principal subroutines, which in turn control different segments of the emission-factor "assembly line." The CONSEC component is simply an interpreter and validator of control inputs (integer variables telling the model how certain parameters and input and output data are to be processed). The ONESEC component sets the model run for a one-time (i.e., nonrecursive) computation over one or more of the input parameters. The PARSEC component checks the values of the input parameters (number of vehicle speeds entered, analysis year(s), region code, distribution of VMT by engine operating mode, ambient temperature, and any additional inputs required for specification of scenarios that consider auxiliary engine loads, trailer towing, humidity, or exact altitude). The REGMOD component adjusts mileage/registration arrays by model year to develop an appropriate fleet age and VMT accumulation profile for the analysis years. The EFCALX component actually computes the composite emission factors for those years, accessing all appropriate data blocks for basic rates and correction coefficients. Finally, the OUTPUT component organizes the emission-factor report according to one of four possible output formats prespecified by the user. Despite its apparent complexity (more than 70 subroutines and functions and hundreds of data-block records), MOBILE3 is really just a sophisticated accounting model that identifies its target very quickly and runs efficiently (only a few seconds' CPU time per scenario). The FORTRAN source code consists of more than 13,000 lines, but well over half of these represent documentation (comment statements). A more compact organization of the program's data blocks could have shrunk the code still further, but at a considerable loss of interpretive clarity to the user. Figure 12 shows sample output from MOBILE3.

The MOBILE3 model contains no "default" estimates of total vehicular registrations to permit computation of vehicle-miles by vehicle type through the model. Thus, all region-specific vehicular activity data and definition of regional/climatalogical parametric values are exogenous to this model. Such numbers *must* be provided by the user, usually from outputs of travel demand models and climate data specific to the analysis region.

The MOBILE3 model calculates a mean emission factor for each vehicle type, weighted according to the age profile of the fleet for that type. Vehicular emissions-performance projections cover any forecast year through 2020, with possible extension to 2030. The model can use a single default distribution of vehicle registration shares, coupled with default annual-mileage accrual by age of vehicle by type, or it can accept (for all years and scenarios tested in a given run) a user-defined age registration and mileage-accrual mix. The computed factor is then a weighted function of share of total travel by each vehicular type (by age of vehicle).

4.4.2 Incorporation of AP-42 Factors

As stated in Secs. 4.1 and 4.4, MOBILE3 does not permit computation of vehicular emissions of SO_2. Sulfur-compound emissions are a function of the sulfur

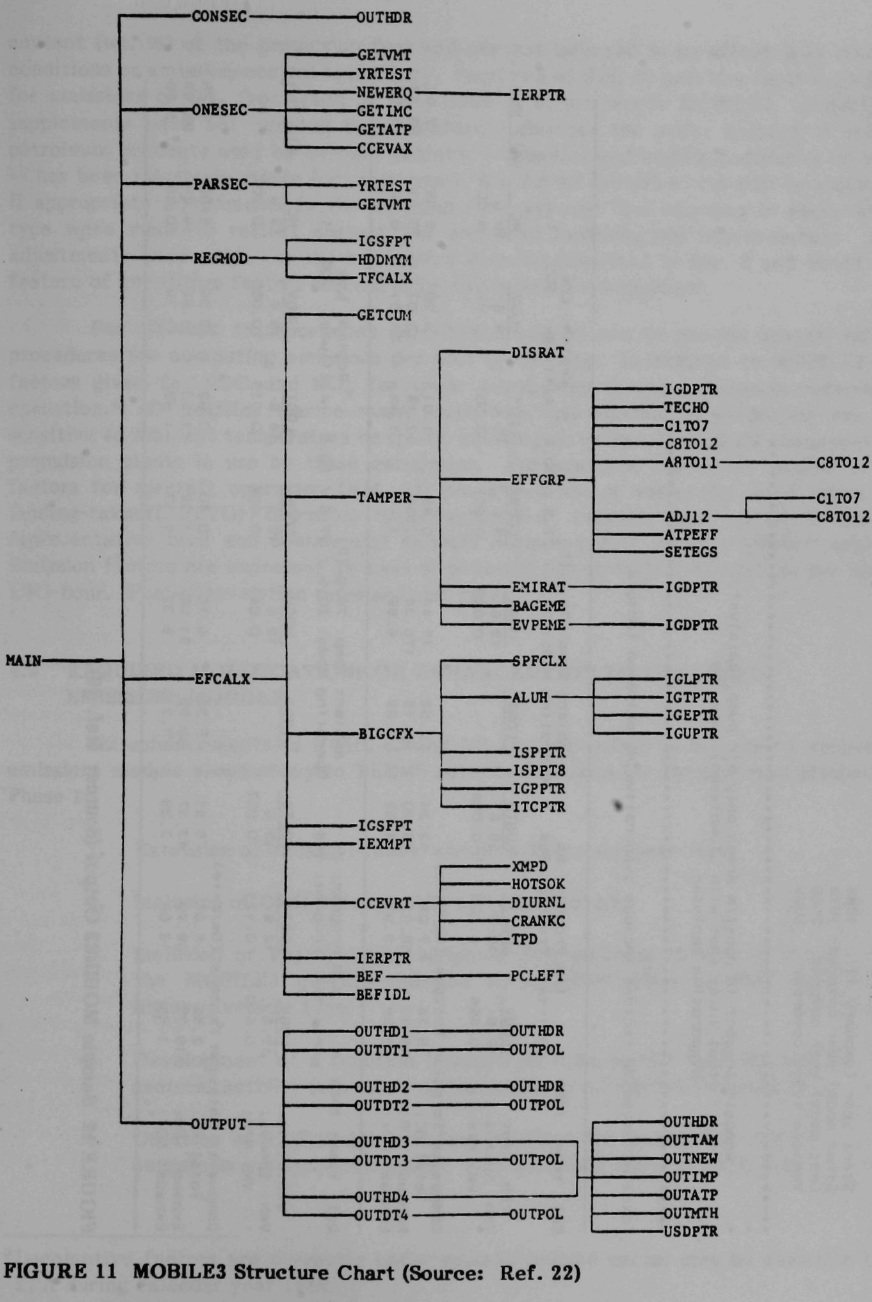

FIGURE 11 MOBILE3 Structure Chart (Source: Ref. 22)

```
Anti-tampering program selected:

    Start year (January 1):    1984
    First model year covered:  1975
    Last model year covered:   2020
    Vehicle types covered:     LDGV

***********************************************************************
*                                                                     *
*      Annual: Inspect in non-I/M areas only air pump, catalyst,      *
*              fuel inlet (not with plumbtesmo), pcv and              *
*              evaporative canister.                                  *
*                                                                     *
***********************************************************************

Total HC emission factors include evaporative HC emission factors.
```

Cal. Year: 1980 — I/M Program: No; Anti-tam. Program: Yes; Ambient Temp: 75.0 (F); Operating Mode: 20.6 / 27.3 / 20.6; Region: Low; Altitude: 500. Ft.

Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
Veh. Speeds:	19.6	19.6	19.6		19.6	19.6	19.6	19.6	19.6	
VMT Mix:	0.666	0.133	0.088		0.040	0.005	0.001	0.060	0.007	
Composite Emission Factors (Gm/Mile)										
Total HC:	5.74	7.68	12.34	9.53	17.44	0.49	1.01	5.30	8.35	7.01
Exhaust CO:	45.75	58.52	76.70	65.75	175.34	1.30	2.16	15.01	29.51	53.13
Exhaust NOX:	2.88	3.37	4.82	3.95	6.56	1.46	1.98	24.91	0.49	4.57

Cal. Year: 1988 — I/M Program: No; Anti-tam. Program: Yes; Ambient Temp: 75.0 (F); Operating Mode: 20.6 / 27.3 / 20.6; Region: Low; Altitude: 500. Ft.

Veh. Type:	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Veh
Veh. Speeds:	19.6	19.6	19.6		19.6	19.6	19.6	19.6	19.6	
VMT Mix:	0.643	0.121	0.087		0.041	0.036	0.015	0.050	0.007	
Composite Emission Factors (Gm/Mile)										
Total HC:	2.52	4.96	5.91	5.36	8.75	0.40	0.62	3.94	6.02	3.35
Exhaust CO:	19.70	39.29	43.37	40.99	91.06	1.32	1.53	11.63	19.81	25.68
Exhaust NOX:	1.69	3.08	3.39	3.21	5.32	1.17	1.45	17.74	0.85	2.93

FIGURE 12 Sample MOBILE3 Output (Source: Ref. 20)

content (wt. %) of the propulsion fuel and are not believed to be affected by ambient conditions or emission-control technology. Section 3 of Ref. 20 provides factors (in g/mi) for emissions of SO_2 from each of the vehicles of interest in MOBILE3. (Subsequent supplements have not updated these factors.) Because the sulfur content of refined petroleum products used by on-road vehicles -- gasoline and middle distillate fuel No. 2 -- has been relatively stable for many years, the AP-42 factors would still be applicable if appropriate adjustments to the assumed fleet-average fuel economy of each vehicle type were made to reflect present and projected technological improvements. Such adjustments were made for the replication exercise described in Sec. 8 and would be a feature of any future factors derived using the basic AP-42 approach.

For off-road transportation activities, Refs. 20 and 21 provide several related procedures for computing emissions per unit of activity. In contrast to MOBILE3, the factors given for VOC and NO_x for these nonhighway source categories (locomotive operation,* air traffic, marine-vessel activities, gas-pipeline compressors) are not sensitive to ambient temperature or speed, but they do reflect the mix of equipment and propulsion plants in use by these categories. For example, the latest version of the factors for aircraft operation (Ref. 21) provides a set of values for each leg of the landing-takeoff (LTO) operation (approach, idle, takeoff, and climbout) for 32 representative civil and commercial aircraft engines and 17 military aircraft engines. Emission factors are expressed as mass of pollutant per aircraft LTO-cycle or per engine LTO-hour. Fuel-consumption rates are also given.

4.5 REQUIRED MODIFICATIONS OR ENHANCEMENTS TO THE TEEMS EMISSIONS MODULE

Six enhancements to MOBILE3 and AP-42 are required to link the recommended emissions module successfully to TEEMS activity forecasts for the test runs planned for Phase 1:

1. Extension of emission-factor computation to the year 2030;

2. Inclusion of California-specific emission factors;

3. Inclusion of appropriately weighted SO_2 emission factors among the MOBILE3 gaseous-emission output multipliers of VMT by highway vehicle type;

4. Development of a function linking fuel consumption by mode and sectoral activity (ton-miles of transport) to off-highway emissions;

5. Creation of FORTRAN interface routines for processing TEEMS outputs in a manner compatible with MOBILE3 requirements; and

*Locomotive factors are currently under review; revised values may be available from EPA during calendar year 1986.

6. Preparation of a state-level report writer. (The allocation procedures embedded in this report writer will be documented in a forthcoming technical memorandum.)

Each of these enhancements is discussed in more detail below.

4.5.1 Extension to 2030

No guidance is available for extending MOBILE3 emission-factor computation beyond 2020. However, with final emission limitations on all highway vehicles expected to be in place by 1995, MOBILE3 factors for each vehicle type do not change from 2010 onward. The activity by each vehicle type is determined in TEEMS (and not computed through the default VMT shares by year from MOBILE3), so emission factors for 2010, 2020, and 2030 are identical for over-the-road emissions of VOCs and NO_x.

4.5.2 California Emissions

The MOBILE3 model does not compute California-specific emission rates on request. Instead, it defers to the EMFAC6D or EMFAC7 model, available only from the California Air Resources Board (CARB) and used exclusively for generating California-specific factors. Discussions with CARB personnel have revealed that the EMFAC7 model is not yet ready for application, but its predecessor model, EMFAC6D, has a logical and data-block structure parallel to and compatible with that of MOBILE3. Therefore, appropriate future zero-mile and emission-deterioration-rate values from EMFAC6D were obtained from CARB and inserted in the relevant MOBILE3 data blocks (replacing the high-altitude factor set) as a special California version of the model. All California-specific emissions from highway transportation are to be computed using this special version.

4.5.3 Adaptation of SO_2 Emission Factors

The AP-42 emission factors for SO_2 from mobile sources must be added to the gaseous-emission-factor data base available from MOBILE3. Reference 20 provides these factors (modified as discussed in Sec. 4.4.2) by vehicle and fuel type for over-the-road automobiles, trucks, and motorcycles. Because the profile of any year's fleet of light-duty cars and trucks is endogenously determined by TEEMS, a separate weighting of factors (i.e., development of a composite emission rate in g/mi) by vehicle type will be required for each forecast year to account for changes in average fuel economy and fuel split. The TEEMS will report the gasoline/diesel split of VMT by highway vehicle type for any forecast; the appropriate SO_2 factor from AP-42, modified according to expected improvements in vehicular fuel efficiency, will be applied to the state-level VMT totals by vehicle type.

4.5.4 Translation from Fuel Consumption to Emissions for Off-Highway Activity

References 20 and 21 report most emission factors for off-highway transportation sources (rail, marine, aircraft, pipeline) as a function or derivative of fuel-consumption rate, which in turn varies according to the mission (operation) being performed, the fleet mix, and the annual average hours of service by specific vehicle types. This level of detail is not replicable in the proposed activity-forecasting procedure (TEEMS). However, FRATE3 (a TEEMS component model) does report projections of rail diesel-fuel consumption in millions of gallons separately for line-haul and switching operations. Similarly, marine activity (ton-miles) and energy use are forecasted by type of operation -- tug-tow (Great Lakes), dry bulk (coastal waterways), and tanker (inland waterways) -- and air-freight energy consumption is projected for both dedicated cargo flights and belly-freight movements (the latter being a share of energy consumed by air passenger operations). Transformation of these energy totals to fuel consumption by fuel type or, for aircraft, LTO cycles, enables direct application of AP-42 emission factors to state-level activity totals.

4.5.5 New Code Required for Interface Routines

Earlier versions of the EPA's mobile-source model provided an option for writing the output to an unformatted data file for easy interface with the outputs of a travel-demand model. Because this option is no longer available in MOBILE3, the TEEMS/MOBILE3 interface procedures (see Sec. 5.1) require that FORTRAN programs be written to manipulate the appropriate records in the (formatted) numeric output. Although this feature does not detract from the capabilities of MOBILE3, it represents an increase in preparation time with respect to the Phase 1 test runs over what would be necessary if MOBILE2 were used.

4.5.6 Report Writer

All state-level transportation emissions results must be consolidated into a single value by NAPAP source category. For example, emissions from gasoline- and diesel-powered light-truck operation must be combined into a single figure. Similarly, each total state transportation-source inventory must ultimately be additive with other NAPAP source categories within a state and with the transportation-source inventories of other states. Codes must be written or modified to perform the appropriate summations and report them out.

5 LINKAGE OF EMISSIONS MODEL TO ACTIVITY MODELS IN TEEMS

This section presents the proposed linkage arrangements between the components of the TEEMS activity models and the MOBILE3 and AP-42 factor components of the emission model. The specific interface mechanisms between each activity component and its associated emission factor component(s) are described.

5.1 TEEMS ACTIVITY-EMISSION MODEL INTERFACE: AN OVERVIEW

Figure 13 identifies the specific activity outputs of the TEEMS transportation-forecasting process and their proposed linkage to MOBILE3 and AP-42 factors. State-level emissions are computed through emission-factor outputs of MOBILE3 (and national-level factors from AP-42) on the basis of state-level activity allocations. The figure clearly shows that both MOBILE3 and AP-42 factors must be used: the former for activity output as vehicle-miles of on-road movement; the latter for activity output as ton-miles and fuel consumption of off-road freight movement, or LTO cycles and fuel consumption of off-road passenger-carrier movement, plus all transportation-related SO_2 emissions.

5.2 PROPOSED PROCEDURE TO PROJECT EMISSIONS FOR EACH ACTIVITY COMPONENT

5.2.1 Nationwide Personal Travel Forecasting Module (SMSA and non-SMSA vehicular travel by households)

The DPTAM component of TEEMS generates nationwide miles of annual travel by personal-household automobiles and light trucks, aggregated from projections of total personal vehicular activity according to household demographics. Because the personal vehicular fleet mix is also forecasted for each household type (as classified in one of 576 demographic cells), total energy consumption and, to a lesser degree, total emissions will be dependent not only on travel activity, but also on the projected national fleet composition with respect to vehicle size and technology.

The portion of household-based VMT accomplished on trips of greater than 100 miles -- assumed by TEEMS to be intercity trips, which will have different emission characteristics -- is also accounted for by the automobile-travel forecast in POINTS (see below) and must be subtracted from each state total to avoid double-counting. The national total of personal (noncommercial) VMT may be allocated to individual states to develop the state-level VMT on the basis of one of the following:

- A trend extrapolation (three-year moving average) of the state share of national VMT for the years 1978-83;[19]

- Average annual gasoline sales by state for 1978-83; or

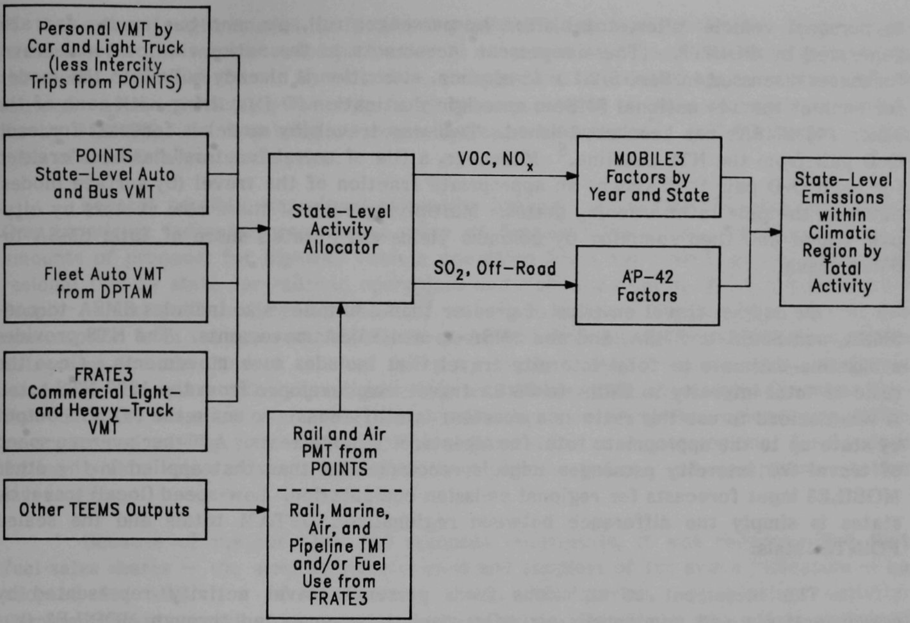

FIGURE 13 TEEMS/MOBILE3 Interface

- A regression procedure to identify possible causative factors and stationary relationships among two or more of the following: fuel sales, average household size by state, index of density of development by state, total population and rank, and (as dependent variable) miles of travel.

After the available options were evaluated in light of the time and resources associated with the Phase 1 test runs, option 1 -- using annual FHWA data -- was recommended to allocate state travel fractions of the personal vehicular movement in DPTAM. Once each state has been assigned a share of national VMT, it must be grouped with other states into a region that is relatively homogeneous with respect to average annual (or seasonal) temperature and humidity and average altitude. These regions correspond to latitude bands, proximity to coastlines (in warmer climates), or both. A MOBILE3 input stream for light-duty vehicles (cars) and all trucks is constructed for each of these regions. Each state is assigned the appropriate MOBILE3 output-factor set for emissions computation.

5.2.2 Passenger-Oriented Intercity Network Travel Simulator

The POINTS model allocates emissions from transportation activity -- in this case, intercity passenger travel -- to states in the most straightforward way. In addition to personal vehicle miles, total miles by passenger rail, air, and bus modes are also generated by POINTS. (These represent increments to the nationwide personal-travel forecasts discussed in Sec. 5.2.1.) In essence, allocation is already built into the model: for each of the 144 national SMSAs, an origin-destination (O-D) pairing with each of the other 143 SMSAs has been established. Two-way travel (by mode) is forecast for each O-D pair from the NTS baseline.[8] Moreover, a file of travel "vectors" has been created for each O-D pair that assigns an appropriate fraction of the travel (by surface modes) between the pair to intervening states. Multiplying each of these row vectors by city-pair travel and then summing by columns yields each state's share of total SMSA-to-SMSA travel.

Of course, travel on trips of greater than 100 miles also includes SMSA-to-non-SMSA, non-SMSA-to-SMSA, and non-SMSA-to-non-SMSA movements. The NTS provides a baseline estimate of total intercity travel that includes such movements. Once the ratio of total intercity to SMSA-to-SMSA travel was developed from the 1977 NTS total, it was decided to use this ratio as a constant in all forecasts to scale the POINTS output by state up to the appropriate total for all intercity movements. A higher average speed of travel for intercity passenger trips is recommended than that applied in the other MOBILE3 input forecasts for regional emission computation. Low-speed (local) travel by states is simply the difference between regionalized DPTAM totals and the scaled POINTS totals.

The increment to emissions from personal travel activity represented by passenger-train and commercial-air miles cannot be computed through MOBILE3 (bus miles use the heavy-duty diesel truck emission factors). Railroad locomotive and aircraft emissions must be estimated by AP-42 emission factors (in units of pounds of pollutant per gallon of fuel or grams per horsepower-hour of operation and pounds of pollutant per engine per LTO cycle, respectively). For aircraft emissions, only flight origin and destination totals by SMSA and the (average) commercial-aircraft mix need be known. The former value is extracted from the POINTS passenger-trip totals and forecasted average airliner load factors; the latter value is obtained from annual data of the Federal Aviation Administration (FAA).

5.2.3 Fleet and Commercial Light-Duty Vehicle Miles

Growth in rental fleet and commercial light-duty vehicle miles with respect to the baseline is computed in TEEMS by a regression procedure that determines the amount of travel activity in each category by appropriate economic and demographic indexes. It is recommended that this total be allocated to states based on total (light-duty) three-year moving average FHWA VMT shares by state for 1978-83. Emissions would then be generated through the regional MOBILE3 factors.

5.2.4 Movement of Goods

The output from FRATE3 used in TEEMS is in the form of VMT by heavy truck by commodity sector (a value extracted from ton-miles of freight movement and average consignment loads by commodity sector); TMT or total fuel consumption is used for each of the other freight modes (rail, air, barge/maritime, and pipeline). Again, it is necessary for the recommended procedure to use ton-miles of activity translated within the model to fuel consumed by rail, ship, and pipeline, in order to apply relevant AP-42 factors. After subtracting the belly-freight component of air cargo (already accounted for by POINTS), the remaining air ton-miles must be translated to LTO cycles on the basis of a load-factor assumption.

Several possible state-level allocation procedures for FRATE3 were examined. One promising indicator was annual sales of "special" fuels (i.e., diesel, with small amounts of propane) for highway vehicle operation (from the FHWA) and of diesel and residual fuel by state for railroad operations and marine bunkering (from the Petroleum Supply Annual published by DOE/EIA).[26] Similar data are available for natural gas consumption from the same source. Other possible definitive variables for various source categories include Class I railroad miles by state, miles of commercially navigable waterways (or square miles of navigable lake surface) by state, interregional commodity-flow data (in tons, but converted to ton-miles by connecting the regional population centroids and scaling the lengths of link segments for each interregional flow vector falling within each region), shoreline and pipeline miles, and compressor-station inventories.

Because of project time and resource constraints, it was recommended that fuel-sales shares -- the most straightforward and simplest of the above indicators -- be adopted for allocation of commercial truck, rail, marine, and pipeline activity. Commercial air operations by state would be based on aircraft-departure data contained in the annual publication, *FAA Statistical Handbook of Aviation*,[27] while general aviation activity would be allocated according to the tabulated totals of hours flown by FAA region and state of based aircraft (published in the same source). Military aviation shares would remain identical to the 1980 baseline.

6 CAPABILITIES OF TEEMS TO DEAL WITH ALTERNATIVE SCENARIOS

The TEEMS is a technology-based modeling package with considerable flexibility and broad capabilities to represent alternative industry-related economic, energy, and transportation scenarios. The features and capabilities of the package include the following:

- Alternative characterizations of future light-duty vehicles (production cost, operating cost, curb weight, fuel economy, and power/performance) as a function of emission-control stringency, success of advanced technologies, and materials composition;

- Definition of vehicle fleet composition for five-year (pre-2005) or ten-year (2000 and later) intervals;

- Forecasting of inter- and intracity passenger travel on the basis of fuel costs and utility-maximization principles;

- Definition of national or regional demographics by household type (income, age of head, number of workers, education, number of cars, SMSA or non-SMSA location) at five- or ten-year intervals;

- Updating of freight and common-carrier passenger modal energy intensities at 10-year intervals;

- Projection of freight-mode shifts due to changes in fuel price, level of service, or both;

- Linking of passenger travel demand to household-level changes in the real cost of travel; and

- Linking of travel-demand outputs to MOBILE3 and AP-42 for development of region-specific mobile-emission factors for each type of activity (in order to capture the climatic effects on transportation emissions in each state).

Because TEEMS will use MOBILE3 as its primary on-road emission-factor-computation algorithm in the test runs of the TG-B emissions model set planned under Phase 1, virtually all current and potential strategies for emission-control baselines in transportation (including final Title II Clean Air Act Standards and I/M programs) are already built into the procedure. Questions have arisen, however, about the capability of a package such as TEEMS that uses MOBILE3 to address potentially more stringent emission controls under future assessments. The following outline treats the anticipated capability of TEEMS to deal with these alternatives.

1. Phasing out of Leaded Gasoline

   - Emission Consequences: Elimination of emissions of total suspended particulate matter (TSP) as lead; possible reduction in CO and HC as "poisoning" of catalysts.

   - Accounting Procedure: Identify proportion of vehicle fleet still using leaded fuel and allocate VMT (by state or region) accordingly; for remainder, reduce implicit MOBILE3 misfueling rate to zero and calculate emissions on that basis. Because there will still be poisoned catalysts in the fleet, take the average of the "misfueled" and "no-lead" factor as the appropriate emission rate for catalyst-equipped cars and trucks.

2. Use of Lower-Volatility Fuels

   - Emission Consequences: Reduction in evaporative HC.

   - Accounting Procedure: The current MOBILE3 model does not explicitly allow fuel-volatility control as an emission-reduction credit. However, the next release of the model is expected to allow for such credits if average seasonal (i.e., summer) volatility is controlled below a fuel Reid vapor pressure of 11.5 lb/in.^{2}

3. Pollution-Control Technologies

   The MOBILE3 model will permit variation from default emission-control factors in order to incorporate the effects of new pollution-control technologies and retrofits.

4. Inspection and Maintenance

   The MOBILE3 model will permit computation of emission-reduction credits due to I/M by state (i.e., relative stringency of each program).

5. Enforcement for New Vehicles

   Modification of zero-mile emission factors is possible in MOBILE3 if certification or audit requirements become more stringent.

6. Tax Credits for New Vehicles

   Net reduction in perceived vehicle cost will lead to higher sales forecasts in the DVSAM car-choice model. The resulting acceleration in vehicle turnover can be explicitly accounted for in MOBILE3 by modification of the age registration fractions.

7. Emission Taxes

Emission taxes could be explicit increments to the operating-cost value in the characterization vector for each of the DVSAM cars: the "dirtier" the vehicle, the higher would be its operating cost, and (presumably) the lower its resulting share of holdings.

8. Demand Changes

Demand variables are explicitly handled in POINTS for intercity travel elasticity. For intracity travel, reasonable estimates as to how mass-transit availability, carpooling, parking and fuel taxes, employer-incentive vanpools, and auto-free zones affect the elasticity of travel by private car are already in hand.

9. Alternative-Fuels Penetration (e.g., methanol, compressed natural gas)

The TEEMS has characterized vehicles using alternative fuels (including expected emission rates) for DVSAM and can explicitly model their share of vehicle fleet (and VMT) by year.

10. Increased Efficiency of Freight Movement

The most important result for freight movement is a lowering of the VMT/TMT ratio. Because FRATE3 explicitly computes TMT by mode, application of this ratio and an appropriate emission factor gives the net result of this ongoing phenomenon. Some projections of increased fuel efficiency due to changes in economies of scale are already built into FRATE3.

11. Phasing out of Heavy-Duty Gasoline Trucks

- Emission Consequences: Significant reduction in VOC emissions.

- Accounting Procedure: Simply zero out (after some agreed future year) the heavy-duty gasoline (HDG) share of VMT, shifting heavy truck operation exclusively to diesel and applying the appropriate MOBILE3 heavy-duty diesel (HDD) emission factor to the additional VMT picked up from HDG.

Because TEEMS uses technology and demographic characterization inputs for five- or (at most) 10-year intervals, the effect of changes over time in control stringency or presumed effectiveness of any of the above scenarios can readily be incorporated into these characterizations for each run of the system without sacrificing important details or information about trends.

7 CALIBRATION OF TEEMS 1980 OUTPUTS TO THE NAPAP INVENTORY: AN EXPLORATORY ALLOCATION OF ACTIVITY AND EMISSIONS

In September 1984, the TG-B Model Users' Group, meeting in Washington, D.C., determined that an important criterion for selection of a forecasting model for transportation-sector emissions would be the ability of such a model to replicate or closely approximate a historical record. Accordingly, ANL made an effort to calibrate the activity-output data from TEEMS for 1980 with the transportation (area) source-category totals of the NAPAP base-year (1980) emissions inventory, defined for procedural purposes as a historical record.

This section describes the conclusions reached about the limitations of the calibration effort and the determination that was made as to which NAPAP totals it was feasible to attempt to replicate. Key differences between the TEEMS and NAPAP approaches are discussed that cause concern about their potential for reconciliation. The calibration (replication) method selected for each relevant source category is described, and the disaggregate results of that replication effort are presented. Some interpretation of these results is also offered.

The NAPAP transportation source inventory for 1980 was extracted directly from the 1980 National Emission Data Survey (NEDS), prepared annually by and for the EPA.[28] Therefore, although it is the NAPAP inventory that is cited here, the discussion is actually directed at the NEDS methodology, which underlies all computations for transportation sources in NAPAP.

7.1 COMPARISON BETWEEN NAPAP/NEDS AND TEEMS

Examination of the method used for the 1980 NAPAP inventory of state-by-state emissions from transportation sources showed it would be generally feasible to calibrate the 1980 TEEMS activity outputs (through appropriate EPA emission factors) to the inventory for personal vehicular travel on an aggregate state basis. Because the NAPAP inventory defines "urban" and "rural" differently from the TEEMS interpretation of "local" and "intercity" travel, the urban/rural split of emission totals by highway source category at the substate level in the NAPAP inventory is not reproducible. Furthermore, replication of heavy-duty truck emissions and emissions resulting from other (off-highway) freight movement below the national level is not feasible, as discussed in Sec. 7.2.6. In any case, close calibration would be undesirable (see below).

These determinations were made in light of a number of built-in incongruities between TEEMS's activity projections and the NAPAP methodology for developing both light-duty and (especially) heavy-duty highway vehicular emissions. The NAPAP (and thereby, NEDS) methodology and some of its inherent problems are fully documented in a recent EPA report.[29] Key differences between this methodology and the TEEMS approach are discussed below.

7.2 ESSENTIAL DIFFERENCES BETWEEN NAPAP AND TEEMS

Table 3 shows the most important differences between the NAPAP and TEEMS procedures for computing statewide emissions from highway vehicles. The implications of these differences for reconciling emissions totals between the two inventories are most significant with respect to (1) basis of highway emissions rates, (2) geographic definition, (3) calculation of vehicle-miles of travel, (4) activity basis of emission factors, and (5) estimation of heavy-truck population.

7.2.1 Basis of Highway Emission Rates

Version 2.0 of the 1980 NAPAP inventory (made available to ANL in March 1984) used the MOBILE2 model in computing emissions, because MOBILE3 was not yet available. MOBILE3 is believed to be the superior model (see Sec. 4.3.2); however, it would be inconsistent to deploy an emission-factor base different from that of Version 2.0 of NAPAP in trying to replicate its totals. Accordingly, the MOBILE2 algorithm and data were used in the TEEMS-activity-to-NAPAP-inventory calibration.

7.2.2 Geographic Definition (urban/rural split)

In the NAPAP inventory, any county is "urban" if it falls within or contains a Metropolitan Statistical Area. (For example, McHenry County, Illinois, would be classified as "urban," even though it is 80% rural in nature.) Similarly, any county not part of an SMSA but containing one or more towns of less than 50,000 population, such that perhaps 60% or more of its vehicular activity is urban in character, is nevertheless a "rural" county in NAPAP. Because NAPAP develops all inventories from state data allocated to the county level, the rural and urban partitioning of the inventory at the state level represents an emission summation over counties preclassified in one or the other category. The TEEMS, on the other hand, models travel on the basis of the trip; whether this trip took place inside or outside an SMSA is not material. Travel is either local (less than 100 miles) or intercity (greater than or equal to 100 miles). Consequently, because TEEMS does not recognize political boundaries, "rural" areas in the model would get a lot of "local" travel (that occurring within towns in such areas), and urban areas would get some proportion of intercity travel. Therefore, the substate geographic travel patterning adopted by NAPAP and TEEMS cannot be reconciled.

7.2.3 Calculation of Vehicle-Miles of Travel

All of the NAPAP vehicular-activity estimates at the county level are based on fuel sales, vehicular registration data, or both. The 1980 NAPAP VMT by county is extracted from the following relationship:

$$VMT_{ij} = FC_{ij} \times MPG_i \tag{7.1}$$

TABLE 3 Key Differences between 1980 NAPAP Inventory Methodology and TEEMS Approach to Statewide Emissions of Highway Vehicles

Parameter	NAPAP Inventory (Version 2.0)	TEEMS Approach
Emission-factor source	MOBILE2	MOBILE3
Urban/rural split	Each county assigned to one or the other category prior to statewise summing	No explicit distinction on a county basis -- however, SMSA vs. non-SMSA travel is extractable (but not reliable except at national level)
VMT	Extracted from allocated county fuel sales and average fuel economy by vehicle class nationwide	Developed from travel-demand split between LDV and LDT according to local (<100 mi) vs. intercity ($\geq$100 mi) operation
Fuel economy	Extracted national average by vehicle class, used together with allocated fuel sales to determine county VMT	Not used in travel-activity calculation -- not relevant to emissions by class as computed through MOBILE3
Truck travel	Split between light- and heavy-duty trucks, based on county registration data	Heavy truck travel developed from a freight-demand model and indexed to (corrected) TIUS data[9]
Direction of allocation of activity	County to state (summation)	Nation to state (Fractional proportion using FHWA VMT share or NAPAP LDV + LDT SO_2 shares for 1980)

where:

VMT_{ij} = Total miles of travel by vehicle class i (LDV, LDT, HDGV, or HDDV) in county j;

FC_{ij} = Gasoline and diesel fuel consumption in gallons (from FHWA state-level sales data) allocated to county j according to that county's share of total state registrations of vehicle class i; and

MPG_i = National average fuel economy (mi/gal) for vehicle class i, derived from the quotient of national miles traveled by class i and total national fuel consumption by class i (from FHWA data).

Thus, NAPAP does not model or attempt to replicate travel activity. Nor is it sensitive to household-based demand for transportation fuels as a function of vehicular utilization and average efficiency. It could assign too little VMT to counties with intensive corridor activity but relatively few vehicle registrations (e.g., Grundy County, Illinois) and too much to counties in which a large population of certain vehicle categories (e.g., trucks) is registered in a depot but not operated. The predesignation of a county as "urban" or "rural" means that such errors are ineluctably propagated in the final statewide tallies.

Again, TEEMS assesses demand for travel at the level of the decision unit (household or shipper) and builds VMT totals on the basis of the type of activity demanded. Average fuel efficiencies for personal vehicles are determined endogenously by the model according to demographics, fuel price, and characteristics of vehicle offerings. This approach cannot be reconciled at the substate level with a procedure that must use an extracted national average fuel economy, together with potentially unrepresentative county fuel-sales allocations, to estimate county-level VMT. However, at the state level, the basis of activity calibration -- annual data from FHWA -- is the same for NAPAP and TEEMS. Therefore, state-level activity should be consistent between the two methods.

7.2.4 Activity Basis of Emission Factors

A single set of emission factors is assigned at the county level of aggregation in NAPAP; the TEEMS develops a set of factors for each state, according to whether the modeled travel is local (<100 mi) or intercity ($\geq$100 mi) in nature. After statewide summing of county emissions, NAPAP urban and rural totals for SO_2, VOCs, and NO_x (and CO) cannot be reproduced by TEEMS, because the mix of speeds used in developing the NAPAP county-level emissions would not necessarily be the same as the average speeds for TEEMS local and intercity travel. A strong nonlinearity in the speed/emissions relationship for VOCs also makes aggregate averaging very difficult.

The implications of this discrepancy are illustrated by the speed vs. emission-rate curves of Figs. 14 and 15, adapted from Ref. 30. A high proportion of rural (i.e., higher-speed) operation would skew the average state emission rates high for NO_x and low for VOCs, but not in the same proportion. The greater the departure from "average" operating conditions as represented by the FTP, the more profound these differences will be. For example, applying the VOC, NO_x, and CO factors for an (extracted) average speed of 10 mi/h in County A and summing to the corresponding emissions of County B (with twice the extracted VMT, operating at an average speed of 16 mi/h) causes the average 1980 MOBILE2 NO_x factor for the combined counties to be set too high and the average VOC and CO factors to be set too low to be replicated at the weighted average speed of 14 mi/h. Adding in more counties with varying ranges of difference simply compounds the problem. But even if all "rural" counties had identical average travel speeds (and if all "urban" counties had another), this skewing effect would still be operative, whatever the weighted average speed.

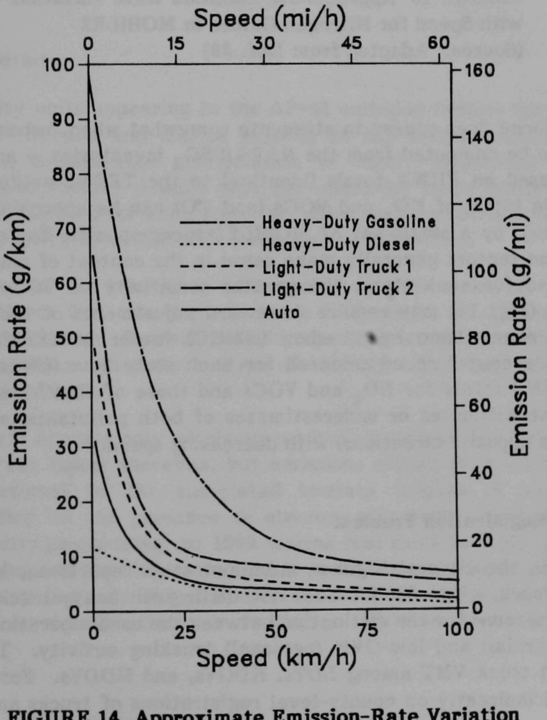

FIGURE 14 Approximate Emission-Rate Variation with Speed for Hydrocarbons in MOBILE2 (Source: Adapted from Ref. 30)

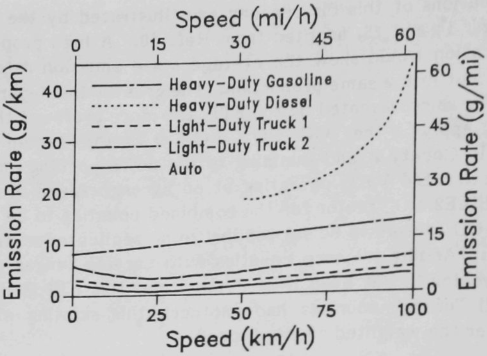

FIGURE 15 Approximate Emission-Rate Variation with Speed for Nitrogen Oxides in MOBILE2 (Source: Adapted from Ref. 30)

Such variance does appear to attenuate somewhat when "urban" and "rural" total VMT -- which can be computed from the NAPAP SO_2 inventories -- are recombined into a single value based on FHWA totals (identical to the TEEMS calibration source). In general, statewide totals of NO_x and VOCs (and CO) can be approximated, at least for LDVs (automobiles), by a single set of MOBILE2 speed-specific factors. Although the extracted emission factors generally make sense in the context of ambient temperature and average speed for each state, the greater sensitivity of VOC emission rates to changes in speed (Fig. 14) may require downward adjustments of the average speed at which the state nonmethane hydrocarbon (NMHC) factor in TEEMS is computed by MOBILE2. The "average" speed selected for each state to minimize the differences between the TEEMS totals for NO_x and VOCs and those of NAPAP simultaneously can produce either overestimates or underestimates of both pollutants, as the two factors diverge rapidly (in opposite directions) with decreasing speed.

7.2.5 The Truck-Registration Problem

In Ref. 19, the Federal Highway Administration reports out VMT splits only by automobile and truck. The FHWA does *not* distinguish heavy-truck from light-truck VMT, nor does it account for the distinction between the usual operations (duty cycles) of high-GVW (commercial) and low-GVW (personal) trucking activity. Therefore, NAPAP must further split truck VMT among LDTs, HDGVs, and HDDVs. For 1980, in NAPAP, this split is based indirectly on county-level registrations of trucks and buses by weight class.*

*There was further manipulation through average mileage accrual by class and average miles per gallon to extract class share of fuel consumption.

The number of trucks registered as heavy trucks (particularly gasoline-powered trucks) significantly overstates the total number of trucks manufactured as such (i.e., actually emitting at HDGV rates) in virtually every state, because owners seek to use a higher GVW rating to qualify their light trucks -- generally in the 6000-8500 lb manufacturers' GVW range -- to carry bigger payloads. Nationwide, the net overcount is about 1.3 million heavy trucks.* This means that NAPAP for 1980 reported out a disproportionately large share of gasoline-powered VMT for heavy-duty trucks and consequently assigned emissions to that class considerably in excess of what actually occurred. (Per-mile emissions of all criteria pollutants except SO_2 can be several times higher for HDGVs than for LDTs at a given speed.) Thus, no single average speed for extracting an HDGV emission rate to calibrate to national totals for all pollutants can be applied unless the imputed VMT from NAPAP is lowered significantly. The amount by which this value should be reduced for each state cannot be determined from the national data base, so state-level calibration is infeasible. (For the same reason, allocation of the corresponding excess LDT activity and emissions by state in the light-duty inventory is also infeasible.)

7.2.6 Off-Road Activity

The activity units appearing in the AP-42 emission factors for off-road vehicles (rail locomotives, aircraft, and marine vessels) do not lend themselves to state-level allocation without considerable manipulation of highly inferential data. For rail operations, fuel consumption in each principal operating mode (switching or line-haul) would have to be estimated for each state, weighted by locomotive type; only a national estimate of such a split can be made from readily available data.

In the case of air transport, LTO cycles or LTO hours of operation may be inferred from national fuel-use totals but are intractable at the state level without detailed information about discrete activity in 1980 at all municipal, private, and military airports within each state by type of aircraft. Time and resource constraints preclude such a data search.

Marine craft operate only within states having navigable waterways or stretches of coastline or Great Lakes shoreline, but emissions arising from such activity are not necessarily proportional to the associated in-state lengths of such waterways or shorelines (depending on the presence or absence of ports). Similarly, the emissions would not be directly proportional to 1980 marine fuel sales by state, because of higher volumes of bunkering and distillate refueling at ports in many states with relatively short extents of waterway (e.g., Alabama) and, thus, relatively little attributable underway fuel use. National-level calibration seems to be the only tractable short-term approach.

*Argonne estimate, based on analysis of TIUS data reported in Ref. 31.

7.3 CALIBRATION PROCEDURES ADOPTED FOR TEEMS TRANSLATION TO NAPAP

7.3.1 Light-Duty Vehicles and Trucks

The TEEMS values for local and intercity travel by state for LDVs and LDTs (see Tables 4 and 5) are multiplied by an average MOBILE2 speed/emission-factor set (SO_2, VOCs, NO_x) appropriate to each category and to the census division and meteorological regime for that state. The imputed VMT for LDT in the NAPAP inventory should be augmented in the same way that national VMT for HDG is diminished. Instead, however, the procedure identifies the average speeds resulting in MOBILE2 emission factors that most closely reproduce the full set of NAPAP totals. Such factors may overstate average truck speeds by state. No attempt is made to disaggregate "urban" from "rural" operation.

7.3.2 Heavy-Duty Vehicles

Values for HDVs have been calibrated to national total emissions only. Due to an error uncovered in the NAPAP (NEDS) procedure, the activity totals generated by TEEMS are the basis of the emission computations.

7.3.3 Off-Road Transportation

Information concerning off-road modes of transportation has been obtained as follows:

Locomotives. The TEEMS/FRATE3 output on national fuel demand (obtained from 1980 EIA data) by type of operation (switching or line-haul) is processed through factors corresponding to those in Sec. II-2 of Ref. 21.

Aircraft. LTO engine-hours of operation are derived from TEEMS fuel-consumption results (calibrated to empirical FAA and EIA data) and multiplied by appropriately weighted values (i.e., aircraft mix is known) from Ref 21, Sec. II-1, for commercial (including freight), general, and military aviation. (Air-freight emissions are developed directly from FRATE3 fuel-consumption totals.)

Marine Vessels. National marine fuel-demand totals (again from EIA) by type and location of operation (from FRATE3) are coupled with appropriate emission factors by fuel and craft (Ref. 21, Sec. II-3).

Pipelines. Data on fuel consumed in 1980 for nationwide natural gas pipeline compressor operation (in British thermal units) are converted to standard cubic feet of

TABLE 4 Vehicle-Miles of Travel by State for Light-Duty Vehicles and Light-Duty Trucks, 1980

State	Light-Duty Vehicles (automobiles): Vehicle-Miles of Travel (10^9 mi)		Composite Emission Factor[a,b]		Light-Duty Trucks: Vehicle-Miles of Travel (10^9 mi)		Composite Emission Factor[a,c]	
	Local	Intercity	NO_x	VOCs	Commercial and Local	Intercity	NO_x	VOCs
Ala.	18.50	3.16	2.83	3.75	4.61	0.55	3.29	3.93
Ariz.	12.80	2.34	2.83	4.62	3.29	0.41	3.29	5.08
Ark.	10.43	2.39	2.83	3.75	2.68	0.42	3.29	3.93
Calif.	85.11	8.84	2.64	4.32	33.91	1.55	2.86	3.39
Colo.	15.61	0.97	2.02	5.92	4.07	0.17	2.28	6.70
Conn.	12.87	2.27	2.86	4.69	3.40	0.40	3.31	5.17
Del.	2.98	0.33	2.83	3.69	0.82	0.06	3.28	3.93
D.C.[d]	1.14	0.74	2.67	4.30	0.40	0.13	3.10	4.61
Fla.	47.74	5.64	2.77	3.87	12.60	0.99	3.21	4.25
Ga.	28.28	3.55	2.83	3.69	7.60	0.62	3.28	3.93
Idaho	4.64	0.34	2.65	4.60	1.30	0.06	3.08	4.95
Ill.	35.46	5.10	2.76	3.93	12.95	0.89	3.20	4.20
Ind.	23.47	5.27	2.88	3.70	6.17	0.92	3.31	3.94
Iowa	13.29	1.96	2.86	3.77	3.24	0.34	3.75	4.09
Kans.	12.87	1.05	2.88	3.70	3.07	0.18	3.65	4.30
Ky.	15.95	3.06	2.90	3.50	3.97	0.54	3.77	3.94
La.	20.37	2.28	2.95	3.37	4.97	0.40	3.37	3.71
Me.	5.19	0.12	2.88	3.70	1.40	0.02	3.33	3.94
Md.	20.01	1.76	2.83	3.69	5.14	0.31	3.68	4.14
Mass.	24.77	0.76	2.95	4.31	6.46	0.13	3.42	4.72
Mich.	45.94	1.37	2.88	3.70	11.24	0.24	3.70	4.19
Minn.	20.94	0.94	2.97	4.06	5.17	0.16	3.76	4.56
Miss.	10.70	2.01	2.95	3.37	2.82	0.35	3.42	3.57
Mo.	25.53	2.65	2.83	3.75	6.23	0.46	3.63	4.25
Mont.	4.24	0.62	2.73	4.62	1.13	0.11	3.08	5.28
Neb.	7.42	0.98	3.10	3.97	1.85	0.17	3.58	4.36
Nev.	4.25	1.39	2.56	4.44	1.01	0.24	2.90	5.08
N.H.	2.79	0.08	2.88	3.70	0.88	0.01	3.33	3.94
N.J.	35.11	1.03	2.95	4.31	8.99	0.18	3.42	4.72
N.M.	7.93	0.69	2.36	4.86	1.82	0.12	2.68	5.55
N.Y.	58.22	3.63	2.86	3.77	14.59	0.64	3.60	4.42
N.C.	28.99	2.51	2.95	3.37	7.33	0.44	3.42	3.57
N.D.	3.47	0.17	3.20	3.49	0.90	0.03	3.65	3.77
Ohio	46.77	6.94	2.83	3.75	11.94	1.22	3.63	4.25
Okla.	16.42	1.48	2.83	3.75	4.74	0.26	3.28	3.93
Ore.	14.42	0.50	3.13	4.03	3.57	0.09	3.60	4.42
Penn.	43.55	7.51	2.83	3.75	11.38	1.31	3.28	3.93
R.I.	3.62	0.47	2.95	4.31	1.02	0.08	3.42	4.72
S.C.	14.54	2.92	2.95	3.37	3.75	0.51	3.42	3.57
S.D.	3.61	0.26	3.03	3.32	1.02	0.04	3.49	3.52

TABLE 4 (Cont'd)

State	Light-Duty Vehicles (automobiles): Vehicle-Miles of Travel (10^9 mi): Local	Intercity	Composite Emission Factor[a,b]: NO_x	VOCs	Light-Duty Trucks: Vehicle-Miles of Travel (10^9 mi): Commercial and Local	Intercity	Composite Emission Factor[a,c]: NO_x	VOCs
Tenn.	23.86	2.78	2.95	3.37	6.07	0.49	3.42	3.57
Texas	80.50	6.59	2.64	3.69	20.92	1.15	3.06	3.93
Utah	6.66	0.97	2.18	5.27	1.72	0.17	2.47	5.99
Vt.	2.43	0.23	2.88	3.70	0.72	0.04	3.33	3.94
Va.	24.78	3.73	2.83	3.69	6.49	0.65	3.28	3.93
Wash.	15.10	0.82	2.86	4.69	4.08	0.14	3.31	5.15
W. Va.	8.95	0.55	2.95	3.37	2.12	0.10	3.42	3.57
Wis.	22.28	1.04	2.93	3.57	5.70	0.18	3.60	4.42
Wyo.	3.29	0.69	2.26	5.06	0.87	0.12	2.57	5.77
Total (U.S.)	977.82	107.45			272.12	18.81		

[a]Obtained from AP-42 or "MOBILE2.5."

[b]Composite emission factor for SO_2, computed on the basis of 98% LDGV and 2% LDDV at 15 mi/gal, is 0.12.

[c]Composite emission factor for SO_2, computed on the basis of 98% LDGT and 2% LDDT at 11 mi/gal, is 0.17.

[d]District of Columbia.

natural gas and multiplied through factors in Ref. 20, Sec. 3.3.2. Electricity-powered compressors (oil and slurry pipelines) are assumed to be served from the national grid and are ignored in 1980.

7.4 RESULTS OF REPLICATION EFFORT

Tables 5 and 6 present the results of the TEEMS-to-NAPAP calibration. State-level emissions by LDVs and LDTs in Table 5 are derived from MOBILE2 factors, generally in the speed range 16-22 mi/h (slightly higher for trucks). For several states, it was necessary to exclude a proportion of VOC emissions because of the speed-sensitivity problem noted in Sec. 7.2.4. In future applications of TEEMS, because "local" travel will be disaggregated from "intercity" travel by mode, appropriate evaporative emissions will be included in all state-level calculations. The essential differences between activity estimates of the NAPAP inventory and TEEMS can generally be detected in the SO_2 emission totals. Uniform underestimation of LDV SO_2 (around 2%) results from the use of a two- (rather than three-) digit factor for SO_2 in TEEMS (i.e., rounding error). The TEEMS shows somewhat higher VMT by LDTs than does NAPAP for California, Delaware, the District of Columbia, Idaho, Illinois, Maine, New Hampshire, South Dakota, Vermont, and Washington. Values of VMT by LDTs are substantially lower only for Nevada and New Mexico. Computed on this basis, national total light-duty transport (LDV plus LDT) emissions from TEEMS differ from the NAPAP national totals by -0.06% for SO_2, 2.04%

TABLE 5 Total Emissions and Percent Differences from NAPAP Values by State for Light-Duty Vehicles and Light-Duty Trucks, 1980

	Light-Duty Vehicles (automobiles)						Light-Duty Trucks					
	Total Emissions (10^3 tons)			Percent Difference from NAPAP Value[a]			Total Emissions (10^3 tons)			Percent Difference from NAPAP Value[a]		
State	SO_2	NO_x	VOCs	SO_2	NO_x	VOCs	SO_2	NO_x	VOCs	SO_2	NO_x	VOCs
Ala.	2.86	67.58	89.54	-1.72	1.82	0.24	0.97	18.73	23.37	-3.98	-9.93	-11.93
Ariz.	2.00	47.23	77.11	-2.06	9.21	2.58	0.69	13.40	20.69	-2.32	1.02	2.12
Ark.	1.70	39.99	53.00	-1.63	4.21	11.72	0.58	11.22	13.40	-3.38	-7.81	-3.04
Calif.	12.43	273.38	447.36	-1.87	3.28	3.34	6.64	111.79	132.51	13.05	4.95	5.18
Colo.	2.19	36.91	108.48	-1.75	-3.22	0.55	0.80	10.66	31.32	2.68	-6.74	3.66
Conn.	2.00	47.74	78.28	-2.11	1.23	9.61	0.71	13.84	21.62	-0.16	-0.19	8.35
Del.	0.44	10.34	13.49	-0.32	2.86	-4.66	0.16	3.16	3.79	7.06	0.91	-7.37
D.C.[b]	0.25	5.53	8.91	-1.77	0.38	2.73	0.10	1.79	2.67	11.74	2.40	0.62
Fla.	7.06	163.00	227.72	-1.91	5.20	1.85	2.55	48.09	63.67	1.95	-0.91	-2.20
Ga.	4.21	99.30	129.47	-1.74	4.45	5.91	1.54	29.71	35.60	3.14	-1.75	-1.83
Idaho	0.66	14.53	25.22	-2.82	1.45	1.45	0.26	4.62	7.42	8.46	4.03	7.03
Ill.	5.36	123.40	175.72	-1.94	1.06	6.28	2.59	48.83	64.08	8.12	1.49	-0.10
Ind.	3.80	91.23	117.20	-1.88	3.84	9.11	1.33	26.02	30.79	-1.46	-5.32	-1.98
Iowa	2.02	48.08	63.38	-1.59	-1.17	6.83	0.67	14.82	16.17	-5.35	-2.38	-1.85
Kans.	1.84	44.21	56.80	-1.55	2.41	1.84	0.61	13.91	15.43	-4.99	-4.66	-5.22
Ky.	2.52	60.77	73.34	-1.62	1.50	1.33	0.84	18.72	19.56	-4.62	3.52	1.94
La.	3.00	73.68	84.17	-1.80	13.51	8.52	1.01	19.95	21.96	-5.05	-0.99	1.69
Me.	0.70	16.84	21.64	-1.86	-0.04	17.97	0.27	5.21	6.16	6.31	0.99	15.95
Md.	2.88	67.92	88.56	-2.14	3.90	8.85	1.02	22.08	24.84	-0.28	6.74	3.34
Mass.	3.38	83.02	121.29	-2.09	2.32	1.58	1.24	24.85	34.29	3.02	1.61	2.64
Mich.	6.26	150.17	192.93	-1.88	8.09	17.92	2.15	46.83	53.03	-2.95	3.95	2.32
Minn.	2.90	71.64	97.94	-2.01	1.07	6.34	1.00	22.10	26.81	-2.30	0.50	2.17
Miss.	1.68	41.33	47.22	-1.57	8.66	10.24	0.59	11.96	12.84	-0.26	0.71	3.62
Mo.	3.73	87.92	116.50	-1.79	0.70	3.27	1.26	26.80	31.38	-4.99	-0.29	-0.10
Mont.	0.64	14.63	24.76	-1.34	3.01	-0.47	0.23	4.22	7.23	2.16	-1.31	11.19
Neb.	1.11	28.70	36.76	-1.59	6.76	5.04	0.38	8.00	9.74	-2.91	-4.00	1.04
Nev.	0.75	15.91	27.59	-1.25	9.09	3.81	0.23	3.99	6.99	-11.71	-10.53	-2.81
N.H.	0.38	9.12	11.72	-3.05	10.30	9.87	0.17	3.28	3.89	20.61	-5.93	-0.93
N.J.	4.78	117.52	171.70	-2.00	5.96	8.67	1.72	34.56	47.70	1.42	0.00	3.09
N.M.	1.14	22.41	46.14	-0.32	8.15	4.70	0.36	5.74	11.88	-8.09	-7.77	-4.72

TABLE 5 (Cont'd)

State	Light-Duty Vehicles (automobiles): Total Emissions (10^3 tons)			Percent Difference from NAPAP Value[a]			Light-Duty Trucks: Total Emissions (10^3 tons)			Percent Difference from NAPAP Value[a]		
	SO_2	NO_x	VOCs	SO_2	NO_x	VOCs	SO_2	NO_x	VOCs	SO_2	NO_x	VOCs
N.Y.	8.18	194.98	257.01	-2.17	1.67	3.25	2.85	60.42	74.18	-1.82	1.49	1.89
N.C.	4.17	102.43	117.01	-1.86	3.68	-0.37	1.46	29.28	30.57	-1.38	-4.41	-8.06
N.D.	0.48	12.86	14.03	-0.94	8.76	8.25	0.18	3.75	3.87	3.36	-0.20	6.54
Ohio	7.10	167.56	222.03	-2.04	1.39	3.54	2.47	52.66	61.65	-1.68	6.15	7.13
Okla.	2.37	55.85	74.01	N.R.[c]	-2.50	4.92	0.94	18.06	21.64	N.R.	9.83	12.38
Ore.	1.97	51.48	66.28	-1.81	10.08	0.78	0.68	14.51	17.82	-1.54	0.68	1.73
Penn.	6.75	159.29	211.07	-1.89	3.13	9.86	2.38	45.90	55.00	-0.67	-5.48	-1.47
R.I.	0.54	13.30	19.43	-2.89	0.73	-0.31	0.21	4.18	5.76	7.53	3.70	3.43
S.C.	2.31	56.78	64.87	-1.75	7.23	4.09	0.80	16.08	16.79	-2.28	-4.08	-7.73
S.D.	0.51	12.92	14.16	-0.64	1.71	-1.87	0.20	4.11	4.15	11.89	4.36	6.06
Tenn.	3.52	86.61	98.95	-1.75	7.57	1.79	1.23	24.72	25.80	-1.39	-1.08	-4.93
Texas	11.52	253.44	354.24	-2.02	1.39	5.98	4.14	74.45	95.62	1.35	-5.83	-0.52
Utah	1.01	18.32	44.30	-2.06	4.73	0.57	0.35	5.15	12.48	-0.77	-1.30	0.08
Vt.	0.35	8.42	10.82	-1.45	4.22	41.52	0.14	2.78	3.29	16.45	4.98	36.40
Va.	3.77	88.95	115.98	-1.95	0.90	5.94	1.34	25.84	30.96	0.48	-5.03	1.78
Wash.	2.10	50.17	82.28	-1.90	-0.26	-2.87	0.79	15.41	23.98	16.25	0.88	6.99
W. Va.	1.26	30.91	35.31	-1.54	6.31	10.71	0.42	8.37	8.73	-5.91	-6.72	1.91
Wis.	3.08	75.32	91.77	-1.95	1.38	-1.02	1.10	23.33	28.64	1.25	-0.27	4.55
Wyo.	0.53	9.91	22.19	-2.36	7.11	1.95	0.19	2.80	6.30	-2.34	2.83	6.66
Total (U.S.)	146.20	3,423.56	4,749.67	-0.91	2.69	4.34	54.52	1,102.25	1,328.07	2.47	3.01	0.87

[a]Positive value (negative value) indicates TEEMS emissions value is greater than (less than) NAPAP value by given percent.

[b]District of Columbia.

[c]N.R. = Not Reported.

TABLE 6 National-Level TEEMS-to-NAPAP Activity Calibration

Transport Mode	NAPAP 1980 Totals (tons/yr) [illegible]	NO_x	VOCs	TEEMS Activity Totals	Average Emission Factor for TEEMS Totals (Factor Source) SO_2	NO_x	VOCs	TEEMS Total Emissions (tons/yr) SO_2	NO_x	VOCs	Percent Difference from NAPAP Totals SO_2	NO_x	VOCs
Heavy-duty truck Gasoline	[illegible]	538,460	642,067	33.931×10^9 mi[a]	0.36 g/mi (Ref. 20, Sec. 3.1.4.3.2)	10.03 g/mi (MOBILE2 at 19.6 mi/h and 65°F)	16.04 g/mi (MOBILE2 at 19.6 mi/h and 65°F)	13,465	375,147	599,937	-13.13	-30.33	-6.56
Diesel	2[illegible]15	2,083,415	358,608	64.422×10^9 mi[a]	2.8 g/mi (Ref. 20, Sec. 3.1.5.2)	28.00 g/mi (MOBILE2 at 19.6 mi/h and 65°F)	4.28 g/mi (MOBILE2 at 19.6 mi/h and 65°F)	198,837	1,832,138	[illegible]03,936	-3.86	-12.06	-15.24
Railroad locomotives (diesel only)	124,267	806,376	195,809	Line Haul: $3,456.724 \times 10^6$ gal	57 lb/10^3 gal	384 lb/10^3 gal	80 g/10^3 gal	98,517	663,691	38,269	–	–	–
				Switching: 433.660×10^6 gal	57 lb/10^3 gal	310 lb/10^3 gal	172 g/10^3 gal	12,359	67,217	37,295	–	–	–
				Total: $3,890.384 \times 10^6$ gal	(Ref. 21, Table II-2-2)	(Ref. 21, Table II-2-2, weighted distribution	(Ref. 21, Table II-2-2, weighted distribution)	110,876	730,908	175,564	-10.78	-9.36	-10.34
Aircraft Commercial	5,020	50,771	49,045	Air Passenger: 2.6044×10^{11} PMT (emissions basis, 2.60×10^6 LTO cycles)	4.01 lb/LTO cycle	38.2 lb/LTO cycle	37.8 lb/LTO cycle	5,200	49,660	49,140	–	–	–
				Dedicated Air Freight: 0.98×10^9 TMT (emissions basis, 50,000 LTO cycles)	4.1 lb/LTO cycle	39.6 lb/LTO cycle	30.3 lb/LTO cycle	103	990	758	–	–	–
				Total: 2.65×10^6 LTO cycles	(Ref. 21, Table II-1-9, weighted averages)			5,303	50,650	49,898	5.64	-0.24	1.74
Civil (general aviation)	784	8,089	26,335	1.12×10^9 gal (emissions basis, 5.3×10^7 LTO-h)	0.3 lb/LTO-h	0.26 lb/LTO-h	1.02 lb/LTO-h	795	6,890	27,030	1.40	-14.82	2.64
Military	624	4,945	11,578	3.50×10^9 gal (emissions basis, 1.3×10^6 LTO-h)	0.89 lb/LTO-h	8.7 lb/LTO-h	11.3 lb/LTO-h	579	5,655	7,345	-7.21	14.36	-36.56
					(Ref. 21, Tables II-1-7, II-1-8, and II-1-9, weighted averages)								
Marine vessels Residual fuel	161,284	26,501	1,262	1.64×10^9 gal (65% cruise, 30% "hotel," 5% full)	239 lb/10^3 gal (S = 1.5%)	50.4 lb/10^3 gal	1.49 lb/10^3 gal	195,980	41,328	1,221	21.51	55.95	-3.33
Diesel fuel	9,343	69,776	10,994	7.76×10^8 gal 70% motorship 30% steamship	27 lb/10^3 gal 28.4 lb/10^3 gal	275 lb/10^3 gal 24.2 lb/10^3 gal	52.2 lb/10^3 ga 3.0 lb/10^3 gal	10,639	77,507	14,527	13.87	-11.08	32.141
Coal fuel	548	27	89	Not defined	–	–	–	–	–	–	–	–	–
					(Ref. 21, Tables II-3-1 and II-3-2, weighted averages)								
Pipeline compressors (natural gas)	–	–	–	6.16×10^{11} scf	0.6 lb/10^6 scf (Ref. 20, Table 3.3.2-1, weighted average)	1075 lb/10^6 scf	44 lb/10^6 scf	185	331,100	13,552	–	–	–
Total	524,186	3,588,360	1,295,787					536,659	3,451,323	1,193,010	2.38	-3.82	-7.93

[a]After adjustment for net overcount of approximately 1.3 million heavy-duty trucks in registered U.S. fleet.

for NO_x, and 3.56% for VOCs. It is not known how much the use of MOBILE3 for the calibration would have affected these differences; however, available information on the ratio of MOBILE3 factors to MOBILE2 factors at a given speed indicates that the TEEMS VOC totals could have been 15-20% higher using MOBILE3, with NO_x higher by a somewhat lesser amount.

Table 6 shows the effect of correcting in TEEMS for overstatement of HDGV and (to a lesser extent) HDDV activity in the 1980 NAPAP inventory: NAPAP totals are substantially underpredicted. Assuming a higher average speed for diesel truck operators -- a logical approach -- could increase diesel NO_x emissions to equivalency with the NAPAP inventory but would reduce VOCs by another 15 to 20%. The TEEMS showed less total fuel consumed in actual rail locomotive operation than was recorded as purchased by railroads in 1980 (due to fueling of ancillary vehicles and loss of 5-10% through fuel-inventory breakdowns); therefore, locomotive emission totals are lower than in NAPAP. By contrast, TEEMS shows somewhat higher emissions for SO_2 and NO_x in marine activity. (Refueling operations for marine vessels are not included in the TEEMS computation, but they are covered under petroleum-marketing operations in the VOC model.) Inclusion of emissions from natural gas pipeline compressors in TEEMS renders aggregate national emission totals over all off-road sources quite comparable with those in NAPAP. Aircraft emissions (except military VOCs) are similar between the two inventories.

8 SUMMARY AND PROSPECT

Candidate transportation-activity-forecasting models have been reviewed in light of eight screening criteria that incorporate the needs of the Task Group B emissions model set and the National Acid Precipitation Assessment Program in general. The Transportation Energy and Emissions Modeling System is recommended as the most suitable forecasting model. The structure and capabilities of the activity-forecasting module of the TEEMS have been discussed in this report.

The MOBILE3 emission-factor-computation algorithm, together with application of appropriate factors from AP-42 documents,[20,21] constitutes the recommended emission-computation procedure for transportation sources of sulfur dioxide, oxides of nitrogen, and volatile organic compounds in the Phase 1 test runs of the model set. The enhancements of MOBILE3 over its predecessor models have been described and its strengths (structure and capabilities) and weaknesses (required enhancements) discussed with respect to the test runs planned under Phase 1. The proposed linkage of AP-42 and MOBILE3 factors to the TEEMS activity module has been partially illustrated by the effort to calibrate 1980 TEEMS activity totals and emission computations to the base-year NAPAP inventory for transportation sources as reported in Ref. 32. (This calibration exercise used MOBILE2, a predecessor of the current model.) Differences from the NAPAP national totals over all transportation-source categories for emissions computed through the modified TEEMS procedure were 1.70% for SO_2, -0.59% for NO_x, and 1.48% for VOCs.

A forthcoming Argonne report will present the regionalization procedure for transportation-activity forecasts developed and incorporated in TEEMS, together with the results of the Phase 1 test runs corresponding to three economic-growth scenarios.

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APPENDIX:

GLOSSARY OF INITIALISMS

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ANL	Argonne National Laboratory
CARB	California Air Resources Board
CPU	Central processing unit
CTS	Commodity Transportation Study
DOE	U.S. Department of Energy
DPTAM	Disaggregate Personal Transportation Activity Module
DVSAM	Disaggregate Vehicle Stock Allocation Module
EIA	Energy Information Administration (DOE)
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRATE3	Freight-Responsive Accounting for Transportation Energy, Version 3
FTP	Federal test procedures
GNP	Gross national product
GVW	Gross vehicle weight
HC	Hydrocarbons
HDD	Heavy-duty diesel
HDDV	Heavy-duty diesel-powered vehicle
HDG	Heavy-duty gasoline
HDGV	Heavy-duty gasoline-powered vehicle
HFC	Highway Fuel Consumption
HGDM	State Level Highway Gasoline and Truck Diesel Fuel Demand Models
HSRI	Highway Safety Research Institute
I/M	Inspection/maintenance
I/O	Input/output
JFA	Jack Faucett Associates
LDT	Light-duty truck
LDV	Light-duty vehicle (automobile)
LTO	Landing/takeoff
MIT	Massachusetts Institute of Technology
NAFDEM	National Freight Demand Model
NAPAP	National Acid Precipitation Assessment Program
NEDS	National Emission Data Survey
NMHC	Nonmethane hydrocarbon
NO_x	Oxides of nitrogen
NPTS	Nationwide Personal Transportation Study
NTS	National Travel Survey
O-D	Origin-destination
ORNL	Oak Ridge National Laboratory
PMT	Passenger-miles of travel
POINTS	Passenger-Oriented Intercity Network Transportation System
SIC	Standard Industrial Classification
SMSA	Standard Metropolitan Statistical Area
SRGP	Short-Range Generalized Transportation Policy Model
TEC	Transportation Energy Consumption

TECNET	Transportation Energy Conservation Network Model
TG-B	Task Group B, "Man-Made Sources" (subsequently redesignated as Task Group I, "Emissions and Controls")
TIUS	Truck Inventory and Use Survey
TMT	Ton-miles of travel
TRANS	Transportation Resource Allocation Study
TRIMS	Transportation Integrated Modeling System
TSP	Total suspended particulate matter
UMOT	Unified Mechanism of Travel
UTPS	Urban Transportation Planning System
VMT	Vehicle-miles of travel
VOC	Volatile organic compound